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CORRECTIONS AND INSERTIONS

Contributors to volume 42 have been invited to send corrections and insertions to be made in their paper, and the volumes have been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 49. paragraph 3, *for* "He realized that on account of the state of his health he could not do as strenuous work in the field as some of his colleagues," *read* He was an unusually vigorous man until an attack of angina occurred in July, 1928.

" 159, line 3 from top, *for* "ibid., September 1928, pages 11-19" *read* Bulletin, West Virginia University Scientific Association, volume 2, number 3, October 1928, pages 11-28.

" 163, line 7 from top, *for* 1812-1913 *read* 1912-1913.

" 369, line 16 from bottom, *for* "Genue" *read* Genus.

" 464, line 10 from top, *for* "250,000" *read* 300,000.

" 464, line 11 from top, *for* "200,000" *read* 250,000.

" 651, lines 6 and 7 from top *for* "page 30 of this MSS" *read* page 645.

" 673, line 10 from bottom, *for* "equ" *read* equivalent.

" 704, footnote, *for* "Thickness of Oriskany and elevation of fault numbers exaggerated for clarity," *read* For clarity, the amount of Oriskany at top of Little Mountain is much exaggerated, dip of fault number 2 considerably reduced, and elevation of fault number 3 increased.

‡‡ Bearing imprint [From BULL. GEOL. SOC. AM., Vol. 42, 1931.]

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE FORTY-THIRD ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT TORONTO, CANADA, MONDAY, TUESDAY, AND WEDNESDAY, DECEMBER 29, 30, AND 31, 1930.

CHARLES P. BERKEY, *Secretary*

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Session of Monday Morning, December 29

The Forty-third Annual Meeting of the Geological Society of America was called to order in Room 22, Mining Building, of the University of Toronto, Toronto, Ontario, Canada, at 10:25 a. m., by President Penrose.

Report of the Council

To the Geological Society of America, in forty-third annual meeting assembled:

The regular annual meeting of the Council was held at Washington, D. C., in connection with the Annual Meeting of the Society, December 26-28, 1929. Special meetings of the Council also were held in New York City on April 5, 1930, and October 11, 1930.

The details of administration for the forty-second year of the existence of the Society are given in the following reports of the officers:

President's Report

To the Council of the Geological Society of America:

The President reports that the Geological Society of America during the year 1930 continued the active career which it has shown since its beginning. Though the Society was founded in 1888 it was not until 1929 that it was incorporated. In the early days of its career incorporation did not seem necessary, but in recent years its growth in activity and membership has made this action desirable in order to facilitate the management of its affairs. The incorporation was not adopted until late

in the year 1929, so that its full effect was not felt until the present year of 1930, but during this period it has been of much assistance to the Society.

The position as President of the Society is largely an honorary one and most of the executive duties are carried on by the Secretary whose report for the year 1930 shows the admirable manner in which he has administered the affairs of the Society. In this work the Treasurer and the Editor have cooperated with him in an able manner; while the Council and the various committees which have been appointed for different purposes have given valuable services. With the growth of the Society its affairs constantly demand more attention, and the duties thrown on the Secretary, the Treasurer and the Editor, become more exacting. The efficient, unselfish and entirely gratuitous manner in which these officers have attended to them commands the appreciation of all the Fellows of the Society. The Editor has filled his position for thirty-eight years, a longer period than any other officer has ever served the Society, and the volumes of the Bulletin of the Society which have been issued under his supervision during that time bear eloquent witness to the care and ability which he has devoted to the duties of his office.

Regarding the Council, it has been a pleasure to have been associated with such an efficient and earnest body of scientific men as those composing it. They travel from all quarters of the United States and Canada to attend meetings, and they give to the affairs of the Society their best thought and services.

The President takes this occasion to call attention to the fact that in many scientific societies the character and ideals of the founders are reflected in later years and generations by those who follow them. This has been particularly true of the Geological Society of America. Those illustrious and far-seeing scholars who founded the Society some forty-three years ago formulated the splendid conception of gathering together the workers in various branches of geologic science so that they might cooperate more efficiently. The results have even surpassed their fondest expectations and hopes, for in creating the Society they formed a nucleus around which in later years affiliated organizations have assembled of their own initiative and have added to its comprehensive influence on geologic research as well as on the intellectual and physical welfare of mankind.

The following list comprises the committees of Fellows of the Society during the year 1930, and also the appointments made for special occasions:

Membership Committee: George R. Mansfield (Chairman), Elwood S. Moore, Eliot Blackwelder.

Committee on Foreign Correspondents: Charles Schuchert (Chairman), Andrew C. Lawson, Arthur P. Coleman, Bailey Willis, Charles P. Berkey.

Finance Committee: Joseph Stanley-Brown (Chairman), W. C. Mendenhall, Elwood S. Moore, Edward B. Mathews.

Publication Committee: Charles P. Berkey (Chairman), Edward B. Mathews, Joseph Stanley-Brown, W. J. Mead, Heinrich Ries.

Penrose Medal Committee on Award: Charles P. Berkey (Chairman), Arthur P. Coleman, Arthur L. Day, W. C. Mendenhall, Reginald A. Daly, Andrew C. Lawson, Rudolf Ruedemann.

Committee on Exchanges: Edward W. Berry (Chairman), Henry S. Washington, Edward B. Mathews.

Committee of Past-Presidents on General Advisory Matters: Arthur Keith (Chairman), Bailey Willis, Heinrich Ries.

Committee on Revision of Publication Rules: Joseph Stanley-Brown (Chairman), Charles P. Berkey.

Committee on Revision of By-Laws: Joseph Stanley-Brown (Chairman), Henry B. Kummel.

Committee to make Nominations in Geology for the $10,000 Annual Award of Popular Science Monthly: Nelson H. Darton (Chairman), David White, W. K. Gregory.

Local Committee for the Toronto Meeting: Arthur P. Coleman (Chairman), Ellis Thomson, A. MacLean, T. L. Walker, C. W. Knight, A. L. Parsons, W. A. Parks, H. C. Rickaby, A. G. Burrows, E. S. Moore, Mrs. W. A. Parks, Mrs. T. L. Walker, Mrs. E. S. Moore.

Dedication of the New Campus and Buildings of the University of California at Los Angeles: Delegate, Bailey Willis.

Semi-Centennial of Case School and Inauguration of William Elgin Wickenden as President of the Faculty: Delegate, S. Prentiss Baldwin.

Inauguration of Homer LeRoy Shantz as President of the University of Arizona: Delegate, William Morris Davis.

Quarter-Centennial Celebration of the Illinois State Geological Survey: Representatives, U. S. Grant, W. C. Mendenhall.

Arthur McQuiston Miller Memorial Services: Representative, Arthur Keith.

Semi-Centennial of the University of Southern California: Delegate, John E. Wolff.

Inauguration of Karl Taylor Compton as President of Massachusetts Institute of Technology: Delegate, Charles Palache.

Centenary of the Societe Geologique de France: Representatives, Nelson H. Darton, Arthur Keith.

Convocation to Commemorate the Fiftieth Anniversary of the Founding of the Experiment Station of Rutgers University: Delegate, Henry Barnard Kummel.

Dedication of the New Buildings of the College for Men of the University of Rochester: Delegate, Herman LeRoy Fairchild.

Fourth Open Meeting of the Mining and Metallurgical Advisory Board: Representative, George H. Ashley.

Seventy-fifth Anniversary of the Founding of the Pennsylvania State College: Delegates, Elwood S. Moore, George R. Wieland.

The Society of Economic Geologists: Delegate, George R. Mansfield.

Joseph A. Holmes Safety Association: Representative, John J. Rutledge.

Committee on Stratigraphic Practice, Principles, and Nomenclature: Representatives, J. J. Galloway, W. H. Twenhofel, B. F. Howell.

Respectfully submitted,

R. A. F. PENROSE, JR.,
President.

SECRETARY'S REPORT

To the Council of the Geological Society of America:

The Secretary's annual report for the year ending November 30, 1930, is as follows:

Meetings.—The proceedings of the Annual Meeting held at Washington, D. C., December 26-28, 1929, have been recorded in volume 41, pages 1-142 of the Bulletin. Those of the Cordilleran Section, pages 143-160 of the Bulletin; of Section E of the American Association for the Advancement of Science, pages 161-180; of the Paleontological Society, pages 181-228; of the Mineralogical Society, pages 229-236 of the same volume.

Membership.—During the last year the Society has lost by death eleven Fellows—Alja R. Crook, Cassius Asa Fisher, John S. Grasty, Oliver P. Hay, Daniel F. Higgins, Frank J. Katz, Peter McKellar, William D. Matthew, C. E. Siebenthal, John L. Tilton, Frank A. Wilder. The names of the thirty-three candidates for Fellowship elected at the Washington meeting have been added to the printed list. There has been one resignation. The present enrollment of the Society is 583.

Twenty-eight candidates for Fellowship and five for Correspondentship are before the Society for election, and a number of applications are under consideration by the Council.

Distribution of the Bulletin.—During the past year there have been sent out to domestic subscribers 215 copies and to foreign subscribers 101 copies of the Bulletin, 33 going to new subscribers. This shows an increase over last year of 7 copies. Eight volumes have been distributed gratis, as follows: The Library of Congress; the Government Geological Surveys of the United States, Canada, and Mexico; the Bureau of Science, Manila, Philippine Islands; the Smithsonian Institution, Washington, D. C.; the Geological Society of America Library, Western Reserve University; the Columbia University Library, New York City. The present exchange list comprises 55 addresses.

Detailed Financial Statement of the Secretary's Office

RECEIPTS

Regular subscriptions	$2,887.00
Irregular sales	673.69
Post and express refunds	103.97
Authors' separates	706.38
Paper stock sold to Judd and Detweiler	103.00
Total receipts from all sources	$4,474.04
Amount forwarded to Treasurer	$4,474.04

RECEIPTS FOR SPECIAL PURPOSES

On account clerical expenses in connection with the Secretary's office, the 1930 program and preparations for the Toronto meeting, gift	$1,500.00

DISBURSEMENTS

On account of administration:	
Printing expenses, Washington meeting	$481.30
Printing for 1930	143.28
Clerical help for 1930	400.00
Postage	138.43
Telegrams and telephone calls	64.38
Addressograph plates	5.53
Car fare	21.77
Notary fees	.50
Binding 4 volumes of the Bulletin	19.50
Office equipment	40.00
Miscellaneous supplies	11.20
Framing photographs	36.40
Total	$1,362.50

On account of Bulletin:	
5,000 Manila envelopes	$58.30
Office expenses	
Post and express charges	257.12
Car fare	.45
Notary fee	.25
Exchange on checks	1.60
Supplies	.15
Telegrams	.56
Total	$318.43

The Secretary is under renewed obligation to President Penrose, who has again made a generous contribution to meet the expenses of the growing work. It has been possible with this support to establish better quarters for the secretarial service and to maintain full-time attendance in the executive office of the Society.

Calls from all sources, which had always been cared for by an office staff engaged primarily on other work, had become a real burden and this change, therefore, has given great relief. Mrs. Howells as assistant to the Secretary has given almost full time and it is largely her intimate acquaintance with the routine of the office and its proceedings that makes it possible for the required work to be done. In addition Miss Medora Hooper has been added to the staff for special duty so that the business of the Society might be transacted without delay or inconvenience at all times. Except for the fine cooperation of these members of the office staff the routine service of the organization could not have been carried on successfully. Such credit as there may be for the secretarial service of the past year belongs to these associates rather than to me.

In securing entirely independent quarters a very important improvement has been made. Columbia University has generously provided a separate room in Schermerhorn Building for office use and has fitted up two storage rooms for the publications and other supplies of the Society. These are by all means the best housing accommodations that the Society has ever had and thus far they have involved no additional expense. The expanded office service, however, is an increased expense and would not have been established at all if it had not been for the continued encouragement of the President of the Society, who has for some years past urged improvement in this respect and has supported it in many practical ways.

The possible difficulty of keeping up so expensive an establishment is fully appreciated and except for this practical encouragement the Secre-

tary would not have felt justified in incurring such obligations. Perhaps, however, the time has come when this Society, with its extensive interests, can not afford to maintain a less efficient service. It must be made possible for those who have business, to transact it promptly. The time has arrived, I am sure, when the organization must face the fact that our responsibilities have grown beyond our primitive machinery for handling them. Although the required financial support is not in sight, it is to be hoped that adequate means may sometime be found.

It is no longer practicable for any one to attend to the rather formidable amount of administrative detail that belongs to the executive offices wholly as a matter of accommodation. This, however, has been done from the founding of the Society, for more than forty years, and it will undoubtedly be continued as long as the present officers will serve. No one hereafter, however, should be asked to take on a burden that has grown to such proportions, without at least a part-time allowance. It is too exacting a task. It absorbs an enormous amount of time.

Such changes must come. The present Secretary must turn over the work that has been in his hands for some years past as soon as practicable. It is his wish for the Society that a still more improved service and a much better home may become a reality at no very distant time. Such a development would add greatly to the dignity and prestige of the Society and, I believe, would insure a correspondingly greater activity and influence.

Respectfully submitted,

CHARLES P. BERKEY,
Secretary.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his report for the year ending November 30, 1930.

RECEIPTS

Balance on hand December 1, 1929		$3,796.48
Annual dues:		
1927 (1)	$10.00	
1928 (5)	50.00	
1929 (19)	190.00	
1930 (443½)	4,435.00	
1931 (2)	20.00	
		4,705.00
Initiation fees (33)		330.00
Life commutations (2)		300.00

Redemption of bonds:			
1 Louisville and Nashville Railroad Co.	1,000.00		
2 Bethlehem Steel Corporation	2,100.00		
On account Chicago Railways	150.00		
		3,250.00	
Interest:			
On investments	2,467.50		
On bank balances	81.70		
		2,549.20	
Amounts added to checks		.50	
Case Library		150.00	
Received from Secretary's office:			
Bulletin sales	3,560.69		
Authors' separates	706.38		
Postage and express refunds	103.97		
Miscellaneous	103.00		
		4,474.04	
			$19,555.22
DISBURSEMENTS			
Secretary's Office:			
Administration	$1,362.59		
Bulletin	318.43		
Allowance	1,000.00		
		$2,681.02	
Treasurer's office:			
Expenses	101.35		
Clerk	150.00		
		251.35	
Publication of Bulletin:			
Printing	4,894.02		
Engraving	734.24		
Paper	1,904.90		
Editing	415.68		
Index	400.00		
		8,348.84	
Mineralogical Society of America		132.00	
Cordilleran Section		133.10	
Purchase of rare volumes		318.27	
Publicity		25.00	
Miscellaneous		94.77	
Purchase of bonds:			
2 Province of Ontario	2,010.00		
2 City of Montreal	2,000.00		
1 Southern Pacific-Oregon Lines	975.00		
2 Delaware and Hudson	1,860.00		
		6,845.00	
Interest on above		58.95	
			$18,888.30
Balance in bank, December 1, 1930			666.92
			$19,555.22

The following securities are owned by the Society at the present time.

	Par value
Stocks:	
10 shares of the capital stock of the Iowa Apartment House Company, Washington, D. C.	$1,000.00
40 shares of the capital stock of the Ontario Apartment House Company, Washington, D. C.	4,000.00
Bonds:	
2 Texas and Pacific Railway Co. First Mortgage 5% bonds	2,000.00
2 Fairmont and Clarksburg Traction Co. First Mortgage 5% bonds	2,000.00
2 Consolidation Coal Company First and Refunding Mortgage 40-year 5% Sinking Fund Gold bonds	2,000.00
3 Chicago Railways Company First Mortgage 5% Gold bonds	3,000.00
2 Southern Bell Telephone and Telegraph Company First Mortgage 5% bonds	2,000.00
1 Commonwealth Edison Company First Mortgage Gold bond	1,000.00
2 American Telephone and Telegraph Company 20-year Sinking Fund 5½% Gold Debenture bonds	2,000.00
2 Baltimore and Ohio Railroad Co. First Mortgage 5% bonds	2,000.00
2 Commonwealth Edison First Coll. Trust 5% bonds	2,000.00
2 Central Railways of Baltimore First Mortgage 5% bonds	2,000.00
2 Canadian Pacific Railway Company 4½% bonds	2,000.00
3 Southern Pacific Railway Company 40-year 4½% bonds	3,000.00
2 Shawinigan Water and Power Co. First Mortgage A bonds	2,000.00
2 Canadian National Railway 40-year 4½% bonds	2,000.00
3 Consolidated Gas, Electric Light and Power Company, Baltimore, 4½% bonds	3,000.00
2 Carolina Power and Light Company 5% bonds	2,000.00
2 Province of Ontario 5% bonds	2,000.00
2 City of Montreal 5% bonds	2,000.00
2 Delaware and Hudson Company First and Refunding Mortgage 4% bonds	2,000.00
	45,000.00
Penrose Gift:	
5 City of Philadelphia 4% loan of Oct. 1, 1920	5,000.00
	$50,000.00

Respectfully submitted,

EDWARD B. MATHEWS,
Treasurer.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The following tables cover statistical data for the forty-one volumes thus far issued:

ANALYSIS OF COSTS OF PUBLICATION

Cost	Average, Vols. 1-35	Vol. 36	Vol. 37	Vol. 38	Vol. 39	Vol. 40	Vol. 41
	Pp. 732, pl. 29	Pp. 707, pl. 10	Pp. 692, pl. 20	Pp. 881, pl. 21	Pp. 1226, pl. 31	Pp. 846, pl. 20	Pp. 872, pl. 22
Letter press	$1,895.32	$2,737.89	$2,852.45	$3,495.67	$4,943.21	$3,682.75	$3,871.44
Illustrations	436.82	528.90	414.56	848.08	1,084.48	623.61	636.28
Paper	404.10	411.96	502.76	670.74	939.42	768.70	801.80
Total	$2,736.24	$3,678.75	$3,769.77	$5,014.49	$6,967.11	$5,075.06	$5,309.52
Average per page	$3.74	$5.06	$5.45	$5.67	$5.68	$6.07	$6.09

CLASSIFICATION OF SUBJECT-MATTER

Volume	Areal geology	Physical geology	Glacial geology	Physiographic geology	Petrographic geology	Stratigraphic geology	Paleontologic geology	Economic geology	Official matter	Memorials	Unclassified	Total
	Number of pages											
1	116	137	92	18	83	44	47	..	60	4	4	593+xii
2	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3	56	41	44	41	32	158	104	..	61	15	1	541+xii
4	25	134	38	74	52	52	14	..	47	32	2	458+xii
5	138	135	70	54	28	51	170	..	71	14	9	665+xii
6	50	111	75	39	71	99	1	..	63	25	4	538+x
7	38	77	105	53	40	21	123	4	66	28	13	558+x
8	34	50	98	5	43	67	58	14	79	8	..	446+x
9	2	102	138	..	44	28	64	16	64	12	..	560+x
10	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11	65	110	21	10	54	31	188	7	71	60	46	651+xii
12	199	39	55	53	24	98	5	5	70	2	..	538+xi
13	125	17	13	24	28	116	42	4	165	32	29	583+xii
14	48	47	48	59	183	118	22	1	80	14	1	609+xi
15	26	124	3	94	36	267	..	..	77	17	3	636+x
16	64	111	78	30	102	141	19	..	67	22	15	636+xiii
17	49	161	41	84	47	294	27	..	71	9	2	785+xiv
18	16	164	141	5	29	246	5	..	68	40	3	717+xii
19	106	108	29	66	30	155	32	..	56	15	20	617+x
20	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22	23	54	28	28	23	403	74	..	63	49	1	747+xii
23	75	52	126	108	19	145	134	..	66	32	1	758+xvi
24	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25	34	211	54	32	156	9	175	..	108	9	22	802+xviii
26	..	72	23	11	56	90	148	..	54	44	6	504+xxi
27	1	59	125	31	146	20	271	2	73	24	5	739+xviii
28	25	273	70	69	78	200	55	39	94	110	14	1005+xxii
29	3	107	62	15	127	169	64	..	73	57	21	679+xix
30	160	3	41	9	5	36	205	16	73	59	50	644+xiii
31	1	80	19	4	13	45	22	21	69	97	79	450+xviii
32	73	47	7	27	63	51	77	17	105	2	37	488+xviii
33	39	166	160	47	97	107	101	3	91	41	31	862+xxi
34	20	256	73	2	39	149	48	..	89	38	64	778+xx
35	44	72	17	83	70	140	269	..	76	46	79	896+xxii
36	26	112	27	59	108	103	77	1	74	116	4	707+xx
37	53	101	8	8	16	111	126	43	74	126	1	667+xviii
38	148	88	17	26	41	265	98	..	73	88	13	857+xxiv
39	25	209	160	185	35	111	228	..	94	129	19	1195+xxx
40	54	126	206	29	16	98	92	..	90	64	47	822+xxiv
41	41	229	16	144	33	171	55	34	117	28	7	842+xxv

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

The foregoing report is respectfully submitted.

THE COUNCIL OF 1930, OF THE
GEOLOGICAL SOCIETY OF AMERICA.

December 29, 1930.

ELECTION OF AUDITING COMMITTEE

The following auditing committee was named from the floor: John B. Reeside, Jr. (chairman), Chester R. Longwell, Joseph T. Singewald, Jr. The committee was directed to make a general report to the Society before the close of the sessions, and submit a written report on the securities in Baltimore after their examination.

ELECTION OF OFFICERS, REPRESENTATIVE, CORRESPONDENTS, AND FELLOWS

The Secretary then read the results of the ballot for officers of the Society for the year 1931, and representative on the National Research Council, and of the ballot for Correspondents and Fellows. The following were declared elected:

President:

ALFRED C. LANE, Cambridge, Massachusetts

First Vice-President:

THOMAS L. WALKER, Toronto, Canada

Second Vice-President:

HENRY B. KUMMEL, Trenton, New Jersey

Vice-President to represent the Paleontological Society:

EDGAR R. CUMINGS, Bloomington, Indiana

Vice-President to represent the Mineralogical Society:

ALEXANDER H. PHILLIPS, Princeton, New Jersey

Secretary:

CHARLES P. BERKEY, New York, New York

Treasurer:

EDWARD B. MATHEWS, Baltimore, Maryland

Editor:

JOSEPH STANLEY-BROWN, Kew Gardens, New York

Councilors (1931-1933):

SIDNEY POWERS, Tulsa, Oklahoma

DONNEL F. HEWETT, Washington, D. C.

Representative on the National Research Council:
(July 1, 1931, to June 30, 1934):

E. H. SELLARDS, Austin, Texas

CORRESPONDENTS

JOHN WALTER GREGORY, LL. D., Sc. D., Professor of Geology, University of Glasgow, Glasgow, Scotland.

VLADIMIR A. OBRUCHEV, Ph. D., Professor, Akademie der Wissenschaften, Leningrad, U. S. S. R.

ALBRECHT PENCK, Ph. D., Sc. D., Professor of Geography, Friedrich-Wilhelms Universität, Berlin, Germany.

HANS W. STILLE, Professor of Geology and Paleontology, University of Göttingen, Göttingen, Germany.

WILLIAM WHITEHEAD WATTS, Sc. D., LL. D., Professor of Geology, Imperial College of Science and Technology, London, England.

FELLOWS

ARTHUR ALAN BAKER, Ph. B., Geologist, United States Geological Survey, Washington, D. C.

GEORGE BROWN BARBOUR, M. A., B. A., Ph. D., Professor of Geology, Yenching University, Peiping, China.

JOHN GREER BARTRAM, B. A., District Geologist, Midwest Refining Company, Denver, Colorado.

EDWARD WILLARD BERRY, A. B., Ph. D., Instructor in Geology, Ohio State University, Columbus, Ohio.

MONROE GEORGE CHENEY, B. S., President and General Manager, Anzac Oil Corporation, Coleman, Texas.

JOSEPH PETER CONNOLLY, A. B., A. M., Ph. D., Vice-President and Professor of Mineralogy and Petrography, South Dakota State School of Mines, Rapid City, South Dakota.

CAREY GARDINER CRONEIS, B. S., M. S., Ph. D., Assistant Professor of Paleontologic Geology, and Curator of Invertebrate Paleontology, University of Chicago, Chicago, Illinois.

LUCIANO JACQUES DE MORAES, Geologist, Geological and Mineralogical Survey of Brazil, Rio de Janeiro, Brazil.

CARROLL EDWARD DOBBIN, A. B., Ph. D., Geologist, United States Geological Survey, Washington, D. C.

RICHARD CONRAD EMMONS, B. A., M. A., Ph. D., Assistant Professor of Geology, University of Wisconsin, Madison, Wisconsin.

RICHARD EUGENE FULLER, Ph. B., B. Sc., M. Sc., Ph. D., Assistant Professor of Geology, University of Washington, Seattle, Washington.

GEORGE EDWARD GOODSPEED, S. B., Associate Professor of Geology, University of Washington, Seattle, Washington.

MARCUS ALBERT HANNA, B. A., Ph. D., Geologist and Paleontologist, Gulf Production Company, Houston, Texas.

JAMES EDWIN HAWLEY, B. A., M. A., Ph. D., Professor of Mineralogy, Queen's University, Kingston, Ontario, Canada.

NORMAN ETHAN ALLEN HINDS, B. A., M. A., Ph. D., Assistant Professor of Geology, University of California, Berkeley, California.

SAMUEL HOWELL KNIGHT, B. A., Ph. D., Professor of Geology, University of Wyoming, Laramie, Wyoming.

ARVILLE IRVING LEVORSEN, E. M., Chief Geologist, Independent Oil and Gas Company, Tulsa, Oklahoma.

ERWIN ROBERT POHL, A. B., A. M., Ph. D., Assistant Professor of Geology and Paleontology, Vanderbilt University, Nashville, Tennessee.

RICHARD JOEL RUSSELL, A. B., Ph. D., Associate Professor of Geology, Louisiana State University, Baton Rouge, Louisiana.

GEORGE GAYLORD SIMPSON, Ph. B., Ph. D., Associate Curator of Vertebrate Paleontology, American Museum of Natural History, New York, New York.

JAMES DONALDSON SISLER, A. B., State Geologist of West Virginia, Morgantown, West Virginia.

HANS E. THALMAN, Ph. D., Exploration Geologist and Paleontologist, Royal Dutch and Shell group, Puerto Mexico, Mexico.

ROBERT CHARLES WALLACE, M. A., Ph. D., President, University of Alberta, Edmonton, Alberta, Canada.

PERCIVAL SIDNEY WARREN, B. A., Ph. D., Associate Professor of Geology, University of Alberta, Edmonton, Alberta, Canada.

JAMES MARVIN WELLER, B. S., Ph. D., Paleontologist, Illinois State Geological Survey, Urbana, Illinois.

BRADFORD WILLARD, A. B., A. M., Ph. D., Associate Geologist, Pennsylvania Topographic and Geologic Survey, Harrisburg, Pennsylvania.

HORACE ELMER WOOD, II, A. B., A. M., Ph. D., Assistant Professor of Geology, New York University, Washington Square, New York, New York.

EMANUEL GEORGE ZIES, A. B., Ph. D., Chemist, Geophysical Laboratory, Washington, D. C.

NECROLOGY

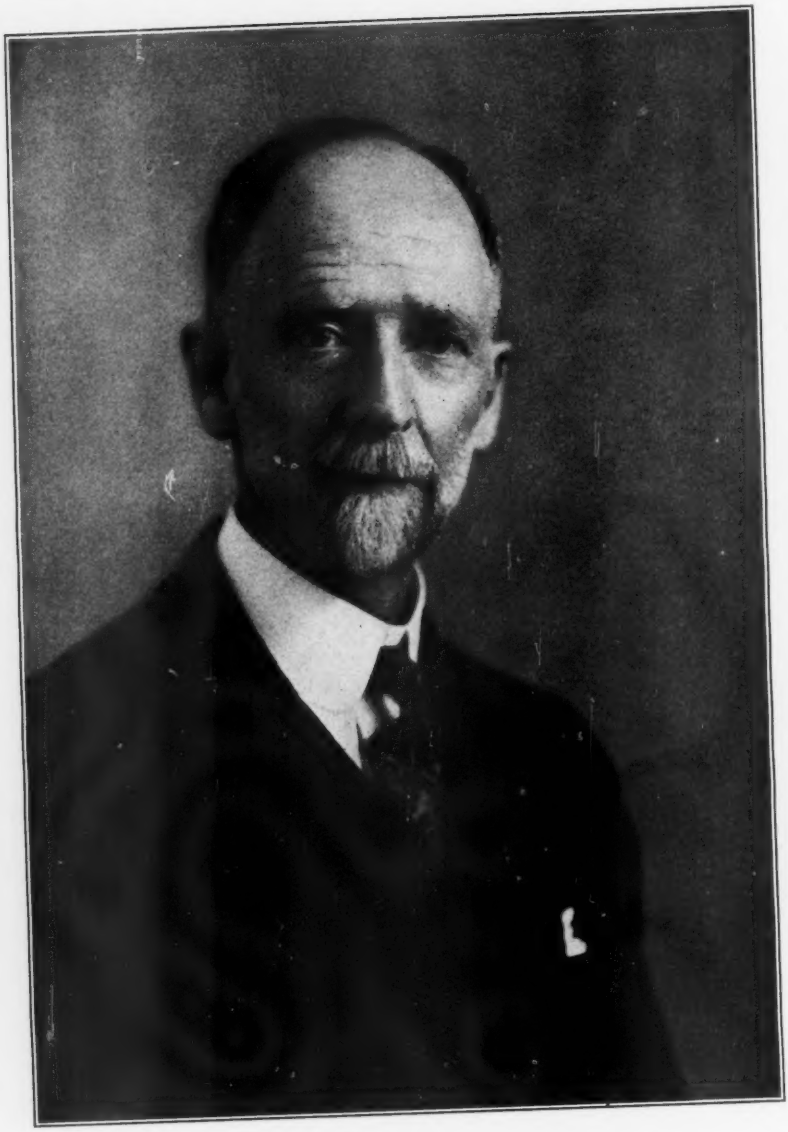
The Secretary announced the deaths of eleven Fellows of the Society, and brief oral tributes were called for as follows:

Alja R. Crook, by Oliver C. Farrington.
Cassius Asa Fisher, by H. W. Lowrie, Jr. (read by the Secretary).
John S. Grasty, by T. Poole Maynard.
Oliver P. Hay, by R. S. Lull.
Daniel F. Higgins, by U. S. Grant.
Frank J. Katz, by George Otis Smith.
Peter McKellar, by T. L. Tanton.
W. D. Matthew, by Henry Fairfield Osborn.
C. E. Siebenthal, by Waldemar Lindgren.
John L. Tilton, by David B. Reger.
Frank A. Wilder, by H. Foster Bain.

MEMORIALS

The following memorials are printed in the Proceedings of volume 42:

Memorial of Alja Robinson Crook, by Oliver C. Farrington.
Memorial of John Sharshall Grasty, by Poole Maynard.
Memorial of Oliver Perry Hay, by Richard Swann Lull.
Memorial of Frank J. Katz, by George Otis Smith.
Memorial of Peter McKellar, by Thomas L. Tanton.



A. R. Crook

Memorial of William Diller Matthew, by Henry Fairfield Osborn.
Memorial of George Perkins Merrill, by Charles Schuchert.
Memorial of Horace Bushnell Patton, by G. M. Butler.
Memorial of Rollin D. Salisbury, by Rollin T. Chamberlin.
Memorial of Claude Ellsworth Siebenthal, by Waldemar Lindgren.
Memorial of John Littlefield Tilton, by David B. Reger.
Memorial of Gilbert Van Ingen, by B. F. Howell.
Memorial of Frank A. Wilder, by H. Foster Bain.
Memorial of Frederick J. H. Merrill, by Charles P. Berkey.

MEMORIAL OF ALJA ROBINSON CROOK[1]

BY OLIVER C. FARRINGTON

Dr. Crook's personality was an engaging one. His interests covered a wide range of subjects, but whatever he touched he adorned with an unfailing optimism and by an apparently easy conquest of what to others might seem insurmountable obstacles. While his contributions to the body of geological science were not extensive, in the organization and development of interest in the science among all classes he achieved outstanding success, the fruits of which may prove to be of more value than had his productions been of a more technical character.

Dr. Crook was of Puritan ancestry, tracing his lineage back to Governor Bradford, John Alden and Priscilla Mullen. To this lineage perhaps he owed his abiding sense of civic and social responsibility, but it was not mingled, to any extent, with the severity traditionally associated with such an ancestry.

Dr. Crook was born in Circleville, Ohio, in 1864, the son of Rev. Isaac and Emma (Wilson) Crook. He was graduated from the Ohio Wesleyan University in 1887 with the degree of A. B. and after a period as superintendent of public schools in Mount Carmel, Ohio, went abroad for study. There he remained for three years, carrying on studies in the universities of Zurich, Berlin and Munich. From the University of Munich he received, in 1892, the Ph. D. degree, his principal work being carried on under Professor von Zittel. His thesis for this degree dealt with some of the Middle Cretaceous fishes of Kansas, by the study of which he established the family of Ichthyodectidae and described a new species of Ichthyodectes. That he was early interested in an activity to which he devoted the later years of his life, is shown by the fact that he studied also during this period in the British Museum and the Museums of the Jardin des Plantes and Brussels. After returning from abroad, Dr. Crook held

[1] Manuscript received by the Secretary of the Society January 29, 1931.

the position of Professor of Natural History at Wheaton College, Wheaton, Illinois, for two years and was then appointed Professor of Mineralogy and Petrology at Northwestern University, Evanston, Illinois. In 1898 his title was changed to Professor of Mineralogy and Economic Geology. The position at Northwestern University he held for thirteen years. His change from paleontology to mineralogy is said to have been made at the request of Dr. Oliver Marcy, Professor of Geology, because mineralogy was at that time without a teacher at the university. There he gave several courses in mineralogy, one in field geology and one in applied geology. During this period he published a few papers on mineralogy. One of these was on the minerals of the Chicago area, which he prefaced with the remark that like the book on the snakes of Ireland which contained the statement that there were no snakes in Ireland, a somewhat similar observation would be true of a paper on the minerals of Chicago. However, by including minerals obtained in the drift, he produced a useful and interesting contribution. Another mineralogical paper of this period was one on molybdenite from Crown Point, Washington. During this period, also, he gathered the materials for a work not published till 1920, which under the title of Guide to the Mineral Collections of the Illinois State Museum contained much useful information regarding the more important mineral species.

Dr. Crook's period of teaching was interspersed with travel in many directions and included mountain climbing as one of his favorite diversions. While in Europe he climbed Mt. Blanc and Mt. Elburz, the highest peak in Europe, and in 1899 made the ascent of Mt. Orizaba in Mexico. He was interested in securing illustrative material for teaching and during the World's Columbian Exposition in Chicago was active in obtaining a large amount of geological specimens from exhibits at the Exposition. During this period also he prepared a number of geological articles for the United Editors' Encyclopedia, the subjects dealt with including coal, diamonds, geology, mining, etcetera.

Through his interest in exhibits Dr. Crook was perhaps gradually drawn to the presentation of subjects by museum methods and in 1906 he embraced the opportunity to become Curator of the Illinois State Museum at Springfield, Illinois. This museum, which had been established chiefly to contain the collections made by the State geologists of Illinois, had never received much public or private attention. Successive geologists or other appointees had served as curators, but during thirty years previous to the incumbency of Dr. Crook, the collections had increased but little in number. At the time Dr. Crook took over the work the museum

was comprised in a single room in the State arsenal and the exhibits consisted largely of great numbers of invertebrate fossils. These had imperfect labeling and there was little about their display likely to attract public interest or be of educational value. To develop the possibilities of such a situation was a work for which Dr. Crook was admirably fitted by temperament and experience. As better housing was one of the most obvious needs, Dr. Crook soon arranged a meeting of the heads of State departments who also required more space, and through the work of this body and constant agitation on the part of Dr. Crook, the present stately and commodious building containing the State museum, library and department of education was constructed and occupied in 1923. Constant increase of the collections of the museum both in geological and other natural history lines and extensions of its service to the people of Springfield and the State of Illinois was, during all his later years, the chief task of Dr. Crook and one in which he succeeded to such an extent as to make it a worthy monument to his labors. The museum which was comprised in a single, poorly lighted room when placed in his charge was expanded under his administration to occupy twelve large, well-lighted rooms and the attendance rose from a few thousand to over one hundred thousand persons annually.

The founding of the Illinois State Academy of Science, now a large and influential organization of more than 700 members, is largely to be credited to the activity and vision of Dr. Crook. It was an outgrowth, to some extent, of his efforts to have the State museum serve a more important function in the State and to become better known than before, but it also arose from his earnest desire to promote interest in science and team work in its development. In its earlier years the Academy led a somewhat precarious existence and in this period the courage and faith of Dr. Crook in its ultimate value and usefulness had much to do with its progress. At Springfield he occupied a strategic position in being able to interest members of the Legislature in the aims and importance of the Academy and he so gained the confidence of the legislators that needed financial support for the Academy was secured.

Dr. Crook served as president of the Academy one term, as secretary for two terms and continuously as librarian.

Besides his scientific activities, Dr. Crook took a prominent part in many civic and religious movements. As a citizen of Springfield, the State capital, he was active in all forward-looking enterprises. At the time of his death, which occurred May 30, 1930, editorials in the leading newspapers of the city bore eloquent testimony to his services to that city

and expressed a deep sense of loss in the passing of so able and useful a citizen. The following glowing tribute to his services and character was paid in an editorial in the Illinois State Register at this time:

"A comprehensive review of his [Dr. Crook's] career elsewhere in this issue of the State Register leaves no doubt as to his ability, energy, courage and multiplicity of useful activities. He was scientist and scholar. He had done much to interest his fellow citizens in the better things of life. He was an educator—a leader in constructive thought. He was the ideal husband and father.

As citizen he met his responsibilities with a fine idealism, aiding Springfield in many ways and always interesting himself in worthwhile things. A scientist of great skill, he was none the less a devout churchman—a Christian who found in science the proof rather than the contradiction of the faith which filled his soul and led him along the pathways of life which he beautified with blossoms of kindness, usefulness, honor and humility."

In 1904 Dr. Crook married Florence Wayne Purdum, of Chillicothe, Ohio. In her he found a helpmeet and companion who devotedly shared his travels and labors. Five children came to bless this union and the family life of the group was ideal. The pain and suffering of Dr. Crook's last illness, the outcome of which seemed likely to be unfavorable from the beginning, were borne by him with a fortitude which carried no hint of complaint or foreboding. To the last he maintained the same cheerful spirit and eager desire to do what he could for the advancement of all things true, honorable and of good report. As was said at the beginning, many subjects interested him, but interest with him always led to action. He was not content merely to become interested. No worthy cause ever appealed to him for help in vain.

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MEMORIAL OF JOHN SHARSHALL GRASTY [1]

BY POOLE MAYNARD

Grasty was a man who raised the profession of geology in the eyes of the business world. He commanded the respect and confidence of big business because of his personality; because he never failed to make his word as good as his bond; because he was more than liberal in his dealings, and because of his knowledge of his subject.

His personality was the gift of a noble inheritance, and with his education, singled him out among men. He was frank in his opinions and he took an uncompromising attitude on the things he thought were right. He had the courage of his convictions. To him life was worth living, and his genial nature endeared him to his many friends.

John Sharshall Grasty was born March 15, 1880, at Versailles, Kentucky, the son of Thomas Percy and Mattie Virginia (White). His

[1] Manuscript received by the Secretary of the Society January 14, 1931.

father was one of the early pioneers in the industrial growth of the South as editor and vice-president of the *Manufacturers Record.*

He was reared in an atmosphere permeated with the optimism of a new South, and he soon realized that the raw materials would play the first important part in the prosperity of his section.

As an undergraduate at Johns Hopkins he soon found his natural environment in the sciences of chemistry, biology, physics and geology. As an undergraduate student he early developed the news value of the results of research in the various departments of the university, and he was a frequent contributor to the local press. He received his A.B. degree at Johns Hopkins in 1904. After a year at Hopkins in postgraduate geology, he took charge of geological exploratory investigations for Baltimore capitalists on the gray ores, or siliceous hematites, of Alabama. The results of this work were published first in the *Manufacturers Record* of May 31, 1906, and illustrated his trend to economic geology and established him in the eyes of the profession as one very capable in the application of science to the development of raw materials.

After a year at Johns Hopkins, Grasty spent a year at Washington and Lee University and at the Massachusetts Institute of Technology in the study of economic geology, and in additional field work in Alabama.

He returned to Johns Hopkins and took his Doctorate in Geology in 1908.

He was an assistant on the U. S. Geological Survey in 1905; geologist with the Maryland Geological Survey, 1906-8; assistant State geologist of Virginia and adjunct professor of economic geology at the University of Virginia, 1908-13; and associate professor at Virginia, 1913-16.

He was given the honorary degree of Doctor of Science by Washington College, Maryland, in 1912.

In recognition of his contributions to science, he was made a Fellow in the Geological Society of America; and Fellow in the American Association for the Advancement of Science. He was a member of the Society of American Military Engineers, American Petroleum Institute, American Institute of Mining, and Metallurgical Engineers, Kappa Alpha, Theta Nu Epsilon, Lambda Pi Sigma, Phi Beta Kappa. Clubs: Johns Hopkins (Baltimore), Colonnade (University, Virginia), Westmoreland (Richmond, Virginia), Chemists (New York). Home: Charlottesville, Virginia.

He made special investigations for the Baltimore and Ohio Railroad, Southern Railway, and Chesapeake and Ohio Railroad. He served as

special geologist with the Alabama Geological Survey, and during the World War as chemical engineer, Ordnance Department.

Grasty did much work on cement materials and limestones, and served as a specialist on rock slides and foundations. For a while his work carried him to structural problems in the midcontinent oil fields. He was chairman of the Geological Committee of the American Manganese Producers Association, and his work on manganese deposits of Virginia was outstanding.

Following an illness of little over a month, Doctor Grasty died at Staunton, Virginia, shortly after noon on Thursday, June 5, 1930.

He is survived by his widow, Elizabeth Montgomery Cochran, and two children, Thomas P. and John Sharshall.

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MEMORIAL OF OLIVER PERRY HAY [1]

BY RICHARD SWANN LULL

Oliver Perry Hay was born in Saluda Township, Jefferson County, Indiana, on the twenty-second of May, 1846, and died on the second of November, 1930, in his eighty-fifth year. Doctor Hay came of pioneer stock, for his grandfather and great-grandfather, of Scottish origin, had settled in Indiana shortly after the War of 1812. Oliver's mother, Margaret Crawford, was of New England lineage, coming by way of Virginia, North Carolina, and Kentucky, so that on both sides his heritage

[1] Manuscript received by the Secretary of the Society January 29, 1931.

Oliver P. Hay

was rich in potentialities which were manifest in his vigorous character and great attainments. Eighty years ago the family migrated to central Illinois where young Hay began his education at a little country school. As he approached manhood he decided to enter the ministry and with this end in view entered Eureka College from which, though interrupted in his course owing to the necessity of self-support, he finally graduated in 1870. However, a strong love of nature overcame his earlier ambition, and after preaching but a single sermon Hay decided on a scientific career. He returned to Eureka College, where he served as professor of natural sciences from 1870 to 1872, also in like capacity at Oskaloosa College, in Iowa, from 1874 to 1876, at Abingdon College, Illinois, from 1877 to 1879, and as professor of biology and geology at Butler College, Indianapolis, from 1879 to 1892. The academic year 1876-77 Hay spent as a graduate student at Yale, but his degree of doctor of philosophy was granted by the University of Indiana in 1884.

Hay's interest in paleontology commenced when he was at Butler College, and he then began to work on a catalog of the literature which was destined to grow into one of his most important, if not the most valuable, contribution that he made to our science. His actual field work began with a trip to western Kansas in 1889 or 1890, from which he returned with a good collection of fossils. From this time on paleontology was his only line of research, although his first contribution to that science did not appear until 1895, when he was appointed assistant curator of zoology in the Field Museum of Natural History, Chicago. There he remained until 1897, joining the staff of the American Museum in 1900 as assistant curator of paleontology, and being promoted to associate curator of Chelonia in 1903, a position which he held until 1907, when he retired to do private research. In 1912 Doctor Hay received an appointment as research associate in the Carnegie Institution of Washington, which he held until his final retirement in 1926, at the age of eighty. Even this did not, however, end Hay's active career, for, aided by certain grants from the Institution, he labored on his second great catalog of the fossil vertebrates of North America, which was finally published the year of his death.

Doctor Hay was an indefatigable worker, toiling for long hours, seven days a week, during a life far beyond the proverbial three score years and ten, and the volume and quality of his work was in every way commensurate with his industry.

In spite of all this Doctor Hay found time for other pursuits, chiefly the study of languages, his only real hobby. Thus he had a reading

knowledge of German, French, and classic Greek and Latin, knew some Russian, and was learning Italian during the last three years of his life, all of which aided in the attainment of his vast knowledge of paleontological literature.

In character Oliver Hay was exemplary. His associates all speak of his warm friendliness, his unfailing kindliness of disposition, and his readiness to aid when advice was sought. His anatomical knowledge was vast and his mind analytical, capable of extraordinary concentration, while he exhausted every detail of his problem. Once his opinion was formed, however, he held to it tenaciously and was difficult to move from his final decision.

In 1870 Doctor Hay was married to Mary Emily Howsmon, of Eureka, Illinois, by whom he had four children: William Perry, who is head of the department of biology and chemistry of the high schools in Washington, D. C., Mrs. Mary Minnick, Frances Steele, and Robert Howsmon, all of whom survive him.

Doctor Hay was one of the founders, sometime secretary, and always an active member of the Society of Vertebrate Paleontologists, which afterward merged into the Paleontological Society affiliated with the Geological Society of America. He became a fellow of our Society in 1921. He was associate editor of the *American Geologist* from 1902 to 1905 and a member of several other scientific and learned societies. His work was not spectacular and rarely called for newspaper comment, which after all is not always indicative of highest values, especially in the present instance, for Doctor Hay's publications are always authoritative and accurate, and his colleagues feel that his judgment may be trusted as based on careful analytical thought. Even when on rare occasions one does not agree with his conclusions, one feels, nevertheless, that Doctor Hay's opinion is entitled to the highest respect.

Perhaps the most outstanding of his many contributions are those on the fossil turtles of North America, culminating in the large volume published in 1908, his work on the American Pleistocene, and above all the two catalogs of the fossil vertebrates of North America which together constitute the most valuable reference book in the library of the vertebrate paleontologist and without which his own research would be rendered much more arduous in view of the vast literature which has grown around our subject.

Doctor Hay's first paper on vertebrate paleontology appeared in 1895, but he had already published some 37 articles on recent animals, crustaceans, fishes, amphibians, reptiles, and birds, besides two on geological

subjects. Subsequent to that year, with rare exceptions, his articles were paleontological. Of Hay's published papers there were 24 on fishes, 36 on turtles, 7 on dinosaurs, 41 on mammals, and 6 on man. Of books and articles on the Pleistocene, including much mammalian description, there are 18; on geology and climatology, 7, and 10 of a general character, together with 9 more or less specific reviews, making a total of nearly 200 titles.

One of Hay's most extensive single works was "The Fossil Turtles of North America," published in 1908, a volume of 570 pages, 113 plates, and 704 text figures. This comprehensive work includes a chapter on the osteology of turtles, one on the amount of modification undergone by turtles since their earliest appearance, on the primary and secondary characters, a summary of classification with their time distribution, and the geographical distribution of living turtles. Then follows the systematic part with detailed descriptions of orders, families, genera, and species, critically considered. And here the value, not alone of clear, succinct description, but also of well drawn figures which further clarify the text is evident. The beautifully reproduced plates are from photographs of practically all the typical specimens known from the rocks of North America. Hay's work on the mammals culminated in three volumes on the Pleistocene mammalia. The first one, published in 1923, dealt with those from the States east of the Mississippi River and the Canadian provinces east of longitude 95; the second, in 1924, includes the middle region, and the third, in 1927, the western region with its vertebrated animals. Hay gives us his conclusions regarding the divisions of the Pleistocene, with the stratigraphical and time limits, and a discussion of the times of extinction of Pleistocene species. Then follows the distribution by States of the Xenarthra, Proboscidea, Equidae, Tagassuidae, musk oxen, bisons, and other notable species, together with maps on which are plotted the important localities of each group. The most extensive section treats of the Pleistocene geology of North America and its relation to its vertebrate fossils. The general plan of each of the several volumes is the same, and collectively they total 1,249 pages, 91 maps, 12 plates, and 49 text figures. Hay was greatly interested in the occurrence of man in America found in association with Pleistocene animals as shown by the bones found at Vero, Florida, and the artifacts of Texas, Oklahoma, and New Mexico.

All of these works, morphological, distributional, and systematical, have greatly enriched our knowledge of American paleontology, but by far the most valuable works from the standpoint of vertebrate research are the

"Catalogues of Fossil Vertebrata of North America." Of these the first appeared in 1902 and covered the literature of the eighteenth and nineteenth centuries, while the second in two volumes (1929 and 1930) included the first 28 years of the twentieth century. Collectively these three volumes total 2,858 pages of closely printed references, arranged first under author's titles and then systematically, with cross references. On extended acquaintance one is struck with the great freedom from error, even typographical, which gives a satisfying feeling of reliability. Not only is the actual recording necessary for such a work stupendous, but the careful sifting of synonyms and the logical classification entailing much fresh grouping and new ordinal and family names covering the entire vertebrate phylum are of the utmost importance to research students. The work implies voluminous detailed reading, understanding, and keen analytical thought. These volumes are immortal and will be used and cherished as long as paleontological research endures.

We are grieved at the passing of so useful and lovable a figure; but we rejoice that he was spared far beyond the accepted limit of life and that he used his time and energy to such advantage, with little thought of personal gain. In Oliver Hay pure science had one of its most valued servants.

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Frank J. Katz

MEMORIAL OF FRANK JAMES KATZ [1]

BY GEORGE OTIS SMITH

Frank James Katz gave the best that was in him to applied geology in the Federal service. In the United States Geological Survey, which he entered in 1907 as a geologic aid, he reached the grade of geologist in 1919. In 1925, with the division of mineral resources, of which he was then chief, he was transferred to the Bureau of Mines, where he retained the same position until his death. His geologic assignments included four years in Alaska, five years in New England, and other field seasons in Oregon, Virginia, and Arkansas; and the subjects of his investigations included coal and gold in Alaska, manganese in Virginia, forest examinations in Arkansas under the Weeks Act, and areal mapping in Alaska and several of the States.

He had prepared for this service at the University of Wisconsin, with postgraduate work both there and at the University of Chicago, where he was a fellow in 1906-7. His plan of study had been to specialize in metallurgy, but Professors Van Hise and Leith made their classes so interesting that he gave up that plan and turned to geology. He was born in New York City January 27, 1883, the son of Edward Marc and Alice (Neustadt) Katz, and died in Washington August 21, 1930. In 1913 he married Martha Valiant Wills, of Washington, who survives him.

In his field work for the Geological Survey Mr. Katz attacked the geologic problems involved in his assignments with energy and enthusiasm. He realized that on account of the state of his health he could not do as strenuous work in the field as some of his colleagues, and he was particularly characterized by a patient, persistent, almost meticulous care to present accurately and in detail the results of his investigations. His reports show high ability in the discrimination of essential facts and the drawing of logical conclusions.

Mr. Katz was one of a group of geologists with abundant field experience who were assigned to specialized statistical work in the division of mineral resources of the United States Geological Survey, in order that their training might be brought to bear on the interpretation of the statistics. His studies in this field were devoted especially to abrasive materials, feldspar, and silica, but like the other geologists of the group he acquired a broad knowledge of the country's mineral resources in general. When the activities of the World War made large demands on the mineral industry and the sources of authoritative information were coordinated early in 1918 under the Joint Information Board he was as-

[1] Manuscript received by the Secretary of the Society December 23, 1930.

signed exclusively to this work and served as secretary of the board, whose chairman was Dr. E. S. Bastin. His own special subject of abrasives had taken on large importance in view of their indispensable function in the speeded-up war industries.

Frank Katz was first of all and above all a faithful worker. Painstaking almost to a fault, he made accuracy one of his major contributions to the statistical work, yet he never lost sight of what the figures stood for. His help in coordinating the annual statistical investigations by the United States Geological Survey with the decennial collection of statistics of mineral production by the Bureau of the Census can not be overestimated. He was engaged in this work from 1919 to 1922.

Devoted as he became to the collection and interpretation of mineral statistics, he never forgot his earlier love for geology, and some of his associates believe that he felt it to be a sacrifice of his ambitions when he finally gave all his time to the administration of the statistical work. Yet he was only one of a long line of geologists, beginning with Clarence King and extending down to Lindgren, Bastin, and Loughlin of later years, who laid aside, for a time at least, their geologic research in order to breathe the scientific spirit into the cold and almost lifeless figures of output and reserves. In bringing his training and sound judgment to bear on the preparation of the reports relating to the production of the country's minerals Mr. Katz was a vital factor in maintaining the authoritative quality of the information which has been characteristic of these Government publications for more than a generation. His closest associates bear testimony to his unusual clearness of mind in handling difficult problems and the fairness of the motives that seemed to govern his official and personal relations with others.

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MEMORIAL OF PETER MC KELLAR [1]

BY T. L. TANTON

Peter McKellar, a famous pioneer of the Lake Superior region, passed away peacefully in his ninety-second year, at his home in Fort William, Ontario, on October 29, 1929.

His death was the occasion of mourning among a wide circle of friends; and as a mark of civic esteem the flags of the city were flown at half-mast. During his residence of over sixty years at Fort William he had seen the community grow from a hamlet to the largest city in northwestern Ontario, and he played a prominent part in some of the events which led to this development. He is survived by his widow, formerly Miss Carlotta Burgess Spence, of Toronto, and his sister, Mrs. Margaret McKellar Deacon.

Peter McKellar, born near Glencoe, Ontario, on April 27, 1838, was one of ten children of Capt. Duncan McKellar and his wife, formerly Margaret Brodie. The parents came in 1820 from Argyleshire, Scotland, and settled as agricultural pioneers, first in Kent County, Ontario, and later in Middlesex County. From them Peter inherited a strong physique and qualities of ability, courage, endurance and optimism that characterized the successful pioneers of that period in Upper Canada. Peter spent his early years on the farm, and was educated in the public schools of the county and by supplementary instruction at home. He was of a studious disposition with a natural bent for mathematics, and at a comparatively early age he became interested in surveying and the study of rocks and minerals.

In 1853 the father, Duncan McKellar, headed an exploratory expedition that traversed the north shore of Lake Superior. This circumstance together with the subsequent interest taken by him in explorations for mineral wealth undoubtedly had a marked effect on Peter McKellar's career.

In 1855 the family moved to Ontonagan, Michigan, and from this place the sons accompanied their father on expeditions into various parts of the Lake Superior region. Peter McKellar first came to Fort William in 1863 along with his father and brother Donald; and two years later, he and his brothers John and Donald built a cabin on Black Bay and spent the winter prospecting in that vicinity. On this occasion Peter McKellar discovered rich lead-zinc-bearing veins at Silver Lake and at Enterprise mine, and thus became familiar with the type of deposit that subsequently supported the chief mineral industry of the district.

[1] Manuscript received by the Secretary of the Society February 2, 1931.

Peter McKellar

The first discovery of rich silver ore in this region was made by Peter McKellar during the following summer, in 1866, at Thunder Bay mine, when he was exploring for a canoe route along Current River. This discovery gave the initial impetus to the development of the silver ores for which this district became famous.

The formation of the Thunder Bay Silver Mine Company was the forerunner of many developments on mineral deposits commenced and carried out by the McKellars. Not only did they make the first important finds in northwestern Ontario, of silver, gold, zinc and iron, in quantities sufficient for successful operation, but they were instrumental in building up many of the companies that carried on development work over a long period of years. Included in their properties were: The Enterprise mine, the Zenith zinc mine, the Huronian gold mine, the Atikokan iron range, the Little Pic, the Loon, the Silver Lake, the Partridge, the Osinawe and the Empress mines. They built the first stamp mill to be erected north of Lake Superior at the Huronian gold mine.

Many of their mining ventures were highly successful and for many years following 1866 their business increased in volume and importance. At one time the McKellar brothers owned the greater part of the townsite of Fort William.

Their effort in developing mineral resources was one of the most important elements in opening up the district along the north shore and converting it to the uses of civilization.

Peter McKellar took part in the exploration of the chief canoe routes leading northerly from Lake Superior, and one of his notable contributions was made in 1869 when, with Dr. Robert Bell of the Geological Survey of Canada, he surveyed Lake Nipigon.

During his numerous explorations and prospecting trips he acquired an excellent general knowledge of the geology and mineral resources of the north shore region as is indicated in the "Report of the Royal Commission on Mineral Resources of Ontario," Toronto, 1890.

During an early stage of developments at Thunder Bay mine Peter McKellar took an active part in urging the government to adopt a policy of taxing privately held mineral lands two cents an acre annually in lieu of a royalty imposition that was being considered at that time. McKellar's recommendation was adopted. Shortly afterward the famous Silver Islet mine was discovered on a privately held mining location that had lain idle for 22 years.

His early observations and familiarity with the seasons of navigation in the various harbors along the north shore of Lake Superior enabled

him to give important advice to the officials charged with selecting the terminus for Great Lakes navigation at the time when the first Canadian transcontinental railway was projected. In harmony with Peter McKellar's recommendations Fort William was selected as the terminus. The construction of the Canadian Pacific Railway was initiated at this place in 1875 by the ceremony of turning the first sod. Thenceforth the community entered on a new epoch of development.

At various times over a long period of years Peter McKellar acted either in the capacity of mining engineer or consulting geologist for corporations and private individuals. His private reports made on these occasions have been referred to in several government publications. During 1897-1898 he was superintendent of exploration for the Toronto and Western Mines Development Company operating on Seine River and Lake of the Woods.

During a long career of public service Peter McKellar held a position as councillor of Shuniah municipality, the first municipal organization on the north shore of Lake Superior; and subsequently he was councillor for Neebing municipality for five years and reeve for two years. For some years he was a justice of the peace.

With his brother, the late Donald McKellar, he presented to the city of Fort William, as a memorial to their brother John, the first mayor, the plot of ground on which the McKellar Hospital now stands. Peter McKellar had the honor of laying the corner stone of St. Andrew's Church, the Y. M. C. A. and the First United Church. His last public appearance was during the unveiling of the cairn at Point de Meuron in honor of the voyageurs, soldiers and traders who traversed the Kaministikwia route in early days.

For some years after his marriage, in 1907, Peter McKellar traveled extensively, one of his trips taking him around the world.

His recreations were tennis, golf and bowling. He was a member of the First United Church; prior to the establishment of the United Church of Canada, he had been for many years a devout member of St. Andrew's Presbyterian Church. He was a member of the Kaministiquia and the Canadian clubs in Fort William.

He had been a Fellow of this Society since 1890. He was also a Fellow of the Geological Society of London, a member of the Royal Society of Arts, London; a member of the American Association for the Advancement of Science, and a member of the National Geographical Society of America. He was the founder and first president of the Thunder Bay Historical Society.

WILLIAM DILLER MATTHEW

From a drawing by Peter Van Valkenburgh, November, 1929. Drawn when Professor of Vertebrate Paleontology in the University of California.

Peter McKellar's published works consist of brochures dealing with geological and historical subjects and descriptions of mineral deposits. In his old age he elaborated a theory of continental folding which indicates a remarkable vigor of mind for one who had spent a long life engaged chiefly in practical affairs.

He was a keen observer and an original thinker, and he was held in high esteem by all who knew him. In paying tribute to his former colleague, C. H. Jackson, ex-mayor of Fort William, says: "The late Peter McKellar was a splendid type of citizen and exemplified to the highest degree the class of men who pioneer and build. His courage, ability and optimism were of the finest order and won the admiration and respect of all classes."

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MEMORIAL OF WILLIAM DILLER MATTHEW [1]

BY HENRY FAIRFIELD OSBORN

WITH THE COOPERATION OF WILLIAM KING GREGORY

Vertebrate paleontology as well as the kindred sciences of zoology and geology have suffered an irreparable loss in the death on September 24, 1930, at the age of fifty-nine years, of William Diller Matthew. During the relatively brief period of thirty-five years, from the time of his life as a graduate student in Columbia (1892-1895) to 1927, he had gained an unparalleled rank both in the range and intensity of his knowledge espe-

[1] Manuscript received by the Secretary of the Society January 31, 1931.

WILLIAM DILLER MATTHEW

As Curator of Vertebrate Paleontology in the American Museum of Natural History. Photographed by Julian P. Scott in the year 1926, in Curator Matthew's private study in the American Museum.

cially of the fossil mammalia of the world, and had traveled far and wide in North America, in Central Asia and through the great museums of Europe. As a reward of arduous research and indefatigable industry he had won a position as an investigator of a rank sufficiently high to be recognized in the same year (1919) by election to the Royal Society of Great Britain and the National Academy of Sciences in America, a simultaneous and double honor never achieved in a single year before, to our knowledge.[2]

"Of the many paleontologists whom the writer has known well," writes Charles Schuchert, "Matthew came nearest his ideal of what such a worker should be. He should be fully conversant with the morphology of his fossils and with their occurrence in the field; he should trace the lines of descent, first through the fossils actually studied and later through the results of others; he should have the ability to write well and to express himself clearly; he should be profound in his studies and yet modest; fearless in expressing himself, never seeking a controversy, but, when challenged, meet his antagonist firmly but impersonally; always honest, analytical, unselfish, and kindly disposed. All these qualities Matthew had, and in better balance than most of us." [3]

By heredity, by early educational environment and by subsequent opportunity, Dr. Matthew may be described as one of the most fortunate of men. He was born in Saint John, New Brunswick, February 19, 1871, his father's family being descendants of the Royalists who settled there at the time of the American Revolution; his mother was descended from American Revolutionary ancestors.[4] His father, Dr. George F. Matthew, was a well-known amateur geologist and paleontologist in the best sense. He had amassed from the region of New Brunswick a great collection of Paleozoic plants, invertebrates, batrachian footprints and contributed several interesting papers on these and kindred subjects, the first coming into widespread notice through his discovery of the soft parts of the trilobites.

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[2] It was found after his election to the National Academy of Sciences at Washington that he had not taken out his papers of American citizenship and could not legally become a member of the Academy. His unanimous election by the geologists and paleontologists of the Academy was a mark of the universally high regard in which he was held in the year of his election.

[3] Charles Schuchert: William Diller Matthew, February 19, 1871. to September 24, 1930. American Journal of Science, vol. xx, Dec., 1930, p. 484.

[4] Compare Natural History, Nov.-Dec., 1930, pp. 664-666, the article entitled William Diller Matthew, by William King Gregory, from which the above passages are largely taken.

Of Dr. Matthew's early training under his father and of the important part he played in the development of the science of paleontology, as well as of his personal characteristics, we may quote the following tribute by Sir Arthur Smith Woodward, distinguished paleontologist and former Director of the British Museum of Natural History:

"He inherited the disposition for geological research from his father, and on leaving school proceeded to Columbia University, New York, where he eventually graduated as Ph. D. In the beginning, his inclinations were towards mineralogy and mining geology, and his first scientific paper dealt with topaz from Japan. For three or four years he spent his leisure in studying the crystalline and volcanic rocks of New Brunswick, and he published several valuable results. At the same time, he was an all-round naturalist, and his papers on some American species of the plant *Cuscuta* and on a trilobite *Triarthrus* show an early interest in the world of life. He attracted the notice of Prof. H. F. Osborn, who was then beginning to organize the great department of vertebrate paleontology in the American Museum of Natural History, and in 1897 [1895] he was selected as one of Prof. Osborn's assistants. Thus began his career as a distinguished student of extinct mammals and other higher vertebrates.

"Matthew's first original research at the American Museum was a revision of the earliest remains of Tertiary mammals found in New Mexico, and his paper on the subject published in the Museum bulletin at the end of 1897 showed that these mammals belonged not to one but to two successive faunas, the Puerco and the Torrejon. It was the beginning of a long series of technical descriptions of the remains of Tertiary mammals which appeared in the Bulletin and Memoirs of the American Museum of Natural History, and is interesting as already displaying the keen insight into the bearing of the facts on wide problems which characterises all Matthew's writings. Cope had supposed that the bones of the two rows of the carpus and tarsus in the earliest Tertiary mammals were always directly opposite, and that interlocking began only in later groups. Matthew proved that such interlocking had already begun in the earliest Eocene. . . .

"In a more general way Matthew was also interested in the extinct birds and reptiles. In 1917 he joined Mr. Walter Granger in a valuable description and discussion of the skeleton of a gigantic running bird, *Diatryma*, from the Eocene of Wyoming. With Mr. Barnum Brown he described Megalosaurian Dinosaurs from the Cretaceous of Alberta. He also described part of a skull of the only known horned Pelycosaurian from the Permian of Texas.

"While occupied with this detailed research, Matthew meditated on many general questions which confront the geologist and paleontologist, and he summarized his ideas in two most suggestive publications. The first is entitled 'Climate and Evolution,' in the Annals of the New York Academy of Sciences, volume 24, 1915. The second is a synopsis of lectures in paleontology in the University of California issued in 1928. Our knowledge of the evolution of the land vertebrates of past times is supposed to be scanty because those which inhabited the uplands and forests are scarcely ever represented by fossils. The early mammals are so imperfectly known because they lived in the forest re-

gions of the north—Siberia, Canada, or Alaska—which have not yet been thoroughly explored. Dispersal and evolution are said to be due chiefly to geographical climatic changes. . . .

"Matthew's quiet, lovable personality, delightful sense of humour, and unassuming scholarship made him a welcome guest wherever he appeared in his many travels, and he had a multitude of friends. He retained his Canadian nationality to the end, and was elected a fellow of the Royal Society in 1919." [5]

Another striking tribute is that by William King Gregory, written from the standpoint of a fellow graduate of Columbia University and of a colleague and co-worker in the American Museum of Natural History:

"William, the eldest of a large family, early absorbed the spirit and viewpoint of the natural sciences from his father and came as a graduate student to Columbia University with an exceptional endowment in these lines. He studied geology, mineralogy, and metallurgy under Professors Eggleston, Kemp, and Moses; his earlier papers, beginning in 1892, dealt with a crystallographic study of topaz from Japan, the antennæ and other appendages of trilobites, the intrusive and effusive rocks near New Brunswick, and similar topics. All his subsequent work in vertebrate paleontology was based primarily upon this solid training in geology. After taking Professor Osborn's courses in vertebrate zoology and paleontology, he obtained his doctorate in 1895 and was called to the American Museum of Natural History as assistant in the department of vertebrate paleontology.

"He took a great part in the field and laboratory work of the department, at first under the immediate direction of Dr. J. L. Wortman, later as ssistant curator, curator, and finally as curator-in-chief of the division of geology, mineralogy and paleontology. It was most fortunate for the Museum that from the first he displayed a passionate ardor for keeping the records straight. He had an almost religious veneration for every specimen, no matter how small or unimportant in appearance, of the tens of thousands that passed through his hands, not because of sentimentality but because he was constantly seeing the value and meaning even of small fragments which had been carefully recorded as to precise geologic level and locality. He never wearied of insisting upon the value of facts as compared with theories; he once said that the skeleton of *Phenacodus* was of incomparably greater value than all the hypotheses that had been based upon it.

"He took a keen interest in the problems that were constantly being raised in the attempts to mount fossil skeletons in lifelike poses and that were to be solved only by carefully correlated studies on the postures and skeletons of living animals. During the years before 1905, while the skeleton of the huge *Brontosaurus* was being removed from the matrix and restored and mounted by Adam Hermann and his assistants, Doctor Matthew studied the problems involved in the reconstruction and mounting. Before the limbs and girdles were mounted, he and Walter Granger dissected an alligator, marked the areas of origin and insertion of the limb muscles on the girdles and limb bones,

[5] Arthur Smith Woodward: Prof. W. D. Matthew, F. R. S. Nature, Oct. 11, 1930, no. 3180, vol. 126, p. 575.

and then identified as far as possible the corresponding areas on the bones of the *Brontosaurus;* finally, by means of scale drawings and paper strips representing the muscles, they endeavored to determine the course and direction of the principal muscle masses in so far as they would influence the posture of the limbs and girdles, especially the angulation of the elbows and knees. This was apparently the first application of the data of comparative myology to the mounting of an extinct animal and the studies that Matthew and Granger made at this time led eventually to further developments of these subjects of comparative myology and osteology by other workers in the Museum and elsewhere.[6]

"He identified, catalogued and kept in close touch with tens of thousands of specimens of fossil mammals. He took part in and directed field exploration in many western localities and in Florida, and made extended studies of vertebrates in the museums of Europe and in the field in Mongolia, Java and elsewhere. With this background of practical experience he compiled, and repeatedly revised and extended, faunal lists of all the Tertiary horizons of western North America and took a prominent part in correlating the horizons of different localities with each other and with the fauna of Europe, Asia and other regions. He published a long series of memoirs, bulletins, *Novitates*, etcetera, on the fossil mammalian fauna of North America, especially those of the Puerco and Torrejon, Tiffany, Wasatch, Bridger, White River, Lower Harrison, Rosebud, Sheep Creek and several later formations. In these reports he dealt effectively with the stratigraphic relations of the formation, mode of deposition, ecology of the various groups, revision of species and genera, osteology and allied topics." [7]

UNIQUE TRAINING AS A VERTEBRATE PALEONTOLOGIST

Cope's type collections of Tertiary mammals and other vertebrates constituted the backbone of Matthew's encyclopedic knowledge of the extinct mammalia of North America. Soon after coming to the American Museum of Natural History in 1895, Matthew was sent by Professor Osborn to Philadelphia to catalogue these collections, which had been purchased by the Museum as a gift of the Trustees, pack and ship them to New York. Some years later the Cope Collection of fossil reptilia came to the American Museum and the larger part of this fell into Matthew's hands, although the Testudinata were treated by Dr. O. P. Hay; here Matthew gained his first-hand knowledge of the Sauropoda which served him in good stead in his subsequent popular articles on these animals. His final task of this kind was the assemblage, determination and shipment of the unique Warren Collection accumulated in Boston by Dr. John C. Warren, including the Warren mastodon, the Zeuglodon and

[6] William King Gregory: William Diller Matthew. Natural History, Nov.-Dec., 1930, vol. xxx, no. 6, pp. 664, 665.

[7] William King Gregory: William Diller Matthew, Paleontologist (1871-1930). Science, Dec. 26, 1930, vol. lxxii, no. 1878, pp. 642-645.

other unique specimens, of the older period of vertebrate paleontology in America.

In this way Matthew came to know and admire Professor Cope and began the detailed task of checking Cope's identifications and revising his classifications, which was to occupy him, along with many other matters, for the next thirty-odd years. As far as systematic determination is concerned, he became the successor not only of Cope but of Leidy and of Marsh as well, and it is a most fortunate circumstance in the history of paleontology that his keen and discerning eye and judgment combined in discriminating between the many fine points of specific and generic distinction as well as to the disputed questions of bibliographic priority.

CONTRIBUTIONS TO MAMMALIAN PALEONTOLOGY[8]

Matthew approached mammalian paleontology from the standpoint of a trained geologist and invertebrate paleontologist, profiting by his studies in geology, mineralogy and metallurgy under Professors Eggleston, Kemp and Moses of the Columbia faculty, beginning in the year 1892. His training and inspiration in vertebrate paleontology came to him as an able student of Professor Osborn's courses in vertebrate zoology, comparative anatomy and phylogeny of the vertebrates in the newly founded Department of Biology of Columbia. He obtained his Doctor's degree in 1895 on a geologic thesis under Kemp. Up to this time his nine publications from the years 1892-1895 were all in geology and mineralogy except for his maiden paleontological paper, 1893:3, "On Antennæ and Other Appendages of *Triarthrus beckii*."

Stimulated by the wonderful materials collected for the American Museum by J. L. Wortman in the years 1891-1900, he began both his anatomical and faunal studies, first on the Titanothere foot, second in the revision of the Puerco and Torrejon faunas based on a re-study of the Cope Collections with the aid of the new American Museum collections between the years 1892 and 1896. This was followed in 1899 by his "A Provisional Classification of the Fresh-water Tertiary of the West."

His first love of the very difficult Puerco and Torrejon faunas now known as Paleocene fascinated him by the many obstacles in the way of such research; this archaic mammal period became his outstanding favorite and his last great contribution, to be published posthumously, is his memoir, "Revision of the Paleocene Puerco and Torrejon Faunas," completing these early studies.

[8] Compare William King Gregory's article William Diller Matthew: His contributions to the science of mammals, American Museum Novitates. In press.

More in detail, the succession of Dr. Matthew's work in mammalian paleontology is traced by his colleague, Gregory, as follows:

"The year 1896-97 was devoted to 'A Revision of the Puerco Fauna,' Matthew's first extensive paper on fossil mammals. In this he made certain definite contributions toward the solution of many of the major problems dealt with in his subsequent papers. In this paper he confirms Dr. Wortman's division into two well separated faunas, the Puerco and the Torrejon, which are shown to be as different as any two successive Eocene formations.

"The most important and original parts of the paper are those that deal with the Creodonta, the Condylarthra and the Foot Structure of Basal Eocene Mammals. The creodonts were represented by five families, including the Oxyclaenidæ, a group of genera with a remarkably primitive type of dentition, many of which had been placed among the Primates, but which were now again referred to the Creodonta. To every one of these families Matthew later made important contributions but in this paper only the initial steps were taken by a careful revision of the genera and species. In discussing the Condylarthra of Cope the important observation was made that this group of 'protoungulates,' as they had been called, is 'nearly related to the early Creodonta and its hypothetical ancestral type or types would be strictly Creodont.'

"In the sections on the skeleton of *Euprotogonia* and on the Foot Structure of Basal Eocene Mammals it was pointed out that a review of the structure of the carpus and tarsus of Basal Eocene Primates, Creodonta, Condylarthra, Amblypoda, Edentata, did not support Professor Cope's view that in the primitive carpus and tarsus the proximal and distal rows of bones were arranged in vertical series like 'unstruck bricks.' On the contrary, 'the conclusion to which the study of these feet leads, apart from any theoretical considerations, seems to me to be as follows:

" 'The primitive condition of the carpus was alternating, with the centrale present. By *absorption* of the centrale a serial carpus, except for the lunar-unciform contact, was produced. By fusion of the centrale with the scaphoid the alternating type of carpus would be maintained. That this primitive alternating carpus was preceded by an entirely serial carpus of the type of *Meniscotherium* is quite possible but there is no evidence of it.

" 'In the tarsus we find no evidence to support the theory of primitive serialism. Only in *Euprotogonia*, the most progressive of the group, do we find an approximately serial tarsus and this is accompanied by a slender foot adapted for running, and by reduced side toes. The drift of all the evidence is toward relegating the primitive serial carpus and tarsus back into the unknown Cretaceous.'

"It may be noted that this virtual abandonment of Cope's theory of the origin of the ungulate carpus and tarsus if accepted would greatly weaken Cope's classification of the ungulate orders and his conclusions as to their relationships with each other and with the unguiculates. In the subsequent decades as more and better preserved skeletons of Basal Eocene and Eocene mammals came to light, the correctness of Matthew's conclusion came to be fully realized by other paleontologists.

"In 1898 his bibliography contains no significant entry, partly for the sufficient reason that the author was busy upon three important papers that appeared in 1899. In 'A Provisional Classification of the Fresh-water Tertiary of the West' the faunal lists of the successive horizons had been submitted to Professors Osborn, Cope, Scott and Dr. Wortman for approval or amendment and were based chiefly on Matthew's first-hand studies of the American Museum collections. A partial essay was made at a critical revision of the species. Thus was laid down the first extensive and critical basis for the expanded and revised lists of later years. Critical notes were also made on the so-called Lake Basins and Matthew's analysis of the later Tertiary horizons of the Western States was given.

"His second paper of the year 1899, 'Is the White River Tertiary an Aeolian Formation?' was a brilliant attempt to disprove the classical theory that the great fossil-mammal-bearing horizons of the Western States were ancient 'lake basins.' By cumulative geologic and paleontologic evidence this theory was shown to be untenable, while at the same time the author tried to establish the conclusion that at least the great bulk of the formations had been laid down as wind-blown loess on broad flood-plains or by rivers and streams. Soon afterward Hatcher, Osborn and others accepted at least the negative side of Matthew's paper but laid more stress on the periodic flooding of the 'basins' by rivers or flood-plain overflows."

OBSERVATIONS ON THE ARCHAIC CREODONTS AND MODERN CARNIVORES

Many years before, namely, in 1887, a friendly division of the paleontologic spoils of America had been made between Professors Osborn and Scott, Osborn selecting certain fossil groups for special research and Scott selecting others. Thus it happened that Matthew entered the field which had previously fallen principally to Scott, namely, of the Creodonta and Carnivora, and all the Artiodactyla. In general, it may be said that Matthew fully completed his observations on the Creodonta, Carnivora and Insectivora but did not live to complete monographically his observations on the Artiodactyla, camels, deer, etcetera. As detailed by Gregory:

"The third paper of 1899, 'The Ancestry of Certain Members of the Canidæ, the Viverridæ and Procyonidæ,' was published in collaboration with Dr. J. L. Wortman. The sections by Matthew deal with the affinities of the Oligocene ('Miocene') Canidæ of North America and describe *Phlaocyon* as an ancestor of the Raccoons. Here then was the first of a series of papers on the ancestry of the Tertiary Carnivora, especially the Canidæ and Procyonidæ.

"In 1900 only one short article appeared but in 1901 two important papers were issued. In 'Additional Observations on the Creodonta' Dr. Matthew addressed himself with great success to the problem of clarifying the hitherto confused relationships and classification of the families of the Creodonta, a subject to which he returned at intervals in later papers. The puzzling characters of *Claenodon* of the Arctocyonidæ were carefully analyzed. It was shown (op. cit., p. 19) that 'the Arctocyons were progressing towards the Bear line in all the most distinctive characters of both teeth and feet. But the

wide gap between Lower Eocene and Middle Miocene makes any connection between the two somewhat uncertain. In the Canid line, on the other hand, we have a number of apparently intermediate stages known [leading from the dogs to the bears]. But these intermediate stages can not have been actually in the line of ascent, and even if they are unaltered descendants of more ancient types we still have a gap of some importance unbridged. The connection, moreover, is based on teeth alone. Professor Osborn, in discussing the evolution of the Mammalia, remarks: 'The teeth and feet, owing to the frequent parallels of adaptation, may wholly mislead us if taken alone; when considered together they give us a sure key; for no case of exact parallelism in both teeth and feet between two unrelated types has yet been found or is likely to be' (Osborn, 1893, p. 10). If *Claenodon* be totally unrelated to the Ursidæ, it is an exception to this statement, and as far as I recall, the only one. And yet the evidence is very strong for deriving the Ursidæ from primitive Dogs.' In later years Dr. Gidley again brought up the claims of *Claenodon* to be considered as possibly related to or near the line of ancestry of the bears but was vigorously opposed by Dr. Matthew."

FOSSIL MAMMALS OF THE TERTIARY OF NORTHEASTERN COLORADO

"In the memoir entitled 'Fossil Mammals of the Tertiary of Northeastern Colorado' the theory of lacustrine origin of the White River and Loup Fork groups was attacked in greater detail than in the brief article in the *American Naturalist* and the theory of 'flood-plain playa and aeolian deposition' was defended with a wealth of arguments drawn from field observations and from an analysis of the faunas preserved in these formations. In the 'Analyses and Discussion of the Faunæ' it was shown that 'two distinct facies were presented by the fauna of each horizon [of the White River Oligocene], the characteristic fauna of the clays being widely different from that of the sandstones.' The conclusion is reached (page 371) that 'the analogy of the clay fauna is with that of the modern plains, of the sandstone fauna with that of the modern forests (with some aquatic forms). In the clays we have hares, squirrels (cf. *Tamias*), vesper-mice and Ischyromids (cf. *Cynomys*) as the characteristic rodents; in the sandstones we have beavers. . . .' The analysis was continued throughout the fauna considered by orders and families. The general conclusion (page 372) was as follows: 'The above evidence seems to make it reasonably certain that the clays and sandstones contain respectively a plains and forest fauna, the latter including some aquatic types. And the occurrence of two such faunæ in these circumstances exactly accords with the theory of terrestrial and flood-plain origin of these beds as set forth in the previous section of this paper, while it seems utterly inexplicable on the theory of their lacustrine origin.'

"From the section dealing with the systematic descriptions in this paper only two or three especially interesting items may be noted here. A carefully worked out reconstruction of the skeleton of the primitive canid *Cynodictis gregarius* was given. This animal was so primitive that its skeleton as a whole was strikingly like that of a viverrine with curved backbone, long tail,

short spreading forefeet. In other words, it lacked the cursorial specializations of the later dogs.

"Under the section dealing with the Felidæ one finds a remarkably interesting discussion of the rise of the sabre-like canines of the Sabre-tooth. The idea that the tusks were used as stabbing weapons but used with the mouth closed was refuted by the fact that the special construction of the mandible permitted the jaw to drop even far below the level of the tips of the upper canines. Associated changes, especially in the size and position of the mastoid processes, indicate unusual strength in certain muscles involved in a stabbing movement of the head. The conclusion was reached that their prey consisted of 'large short-necked animals, probably thick-skinned,' and that 'their most advantageous method of attack was to inflict stabbing and ripping cuts at points where an artery could be reached, using their short, broad and powerful forefeet as fulcrums, and probably bleeding the animal to death."

DISCOVERY OF THE GIRAFFE CAMELS

"Passing to the Artiodactyla, the author gave an analysis of the Oreodonts (page 395) from a combined evolutionary and taxonomic viewpoint. By examining his tables, etcetera, one may readily grasp not only the chief contrasts between the principal genera but the successive stages in the differentiation of the more specialized from the less specialized types. This was characteristic of Matthew that while scrupulously accurate as to facts he never lost the evolutionary and chronologic perspective and that he was never satisfied with merely recording differences but insisted on understanding their drift or meaning.

"In the section on the Camelidæ the detailed description of new material is preceded by an analysis of the distinctive characters and of the genera and species of Loup Fork Camels. In the description of *Alticamelus* the giraffe-camel, the following passage occurs: 'The discovery of this specimen introduces to science one of the most interesting instances of convergence yet observed. The effect of extreme height, in order to enable the animal to feed upon the inaccessible foliage of high and thorny shrubs, is obtained in this species, as in the giraffe, by the elongation of the neck vertebræ and the legs. But the giraffe is derived from the early antelopes and *Alticamelus* from early camels and the difference of origin has caused the attainment of the desired result in a somewhat different manner.' The subsequent analysis of the osteologic resemblances and differences between the giraffe-camel and the giraffe is full of meaning and value.

"Thus by the close of Matthew's first five years at the Museum we find that he had already begun to deal in a very constructive way with most of the great problems that continued to engage his energetic interest for the rest of his life. In reading any of his earlier papers one gets the impression that only in a few places could they be considered as superseded or out of date a quarter of a century later, even where much more complete material has since been discovered. This is perhaps because he combined high originality and initiative with a great reserve of conservatism and caution."

MEMOIR ON THE CARNIVORA AND INSECTIVORA OF THE BRIDGER BASIN

"At this point it appears advisable to abandon a chronologic review of his many important publications and to attempt brief summaries in a number of different fields.

"In his subsequent contributions on the Creodonta he described many new species and by means of more and better material was able to settle many questions left open in previous papers. His classification of the group was given in the Memoir on 'The Carnivora and Insectivora of the Bridger Basin, Middle Eocene' (1909), and in 'A Revision of the Lower Eocene Wasatch and Wind River Faunas' (1915). Following Cope, Matthew defined the suborder Creodonta as distinguished from the Fissipedia by such primitive characters as the small simple brain, the separate scaphoid, lunar and centrale, the flat astragalar trochlea, the presence of five digits on the manus and pes (except in more advanced forms), the retention of an entepicondylar foramen on the humerus and of a third trochanter on the femur.

"At first Matthew accepted the grouping of earlier authors into Adaptive and Inadaptive sections, adding thereto a third section, Primitive Creodonts, to contain the Oxyclaenidæ, whose status as creodonts he had been able to confirm. Later he invented the highly useful terms, Procreodi, Acreodi, Pseudocreodi and Eucreodi, which were given in reference to the contrasting characters of the shearing teeth in the different families. In the primitive Oxyclaenidæ the shearing function was not yet concentrated on any of the cheek teeth and they were therefore named Procreodi. To this division the Arctocyonidæ was transferred in 1915, as a result of the discovery of the Lower Eocene genus *Thryptacodon* of Matthew, which clearly tended to connect the Arctocyonidæ with the more primitive family of Oxyclaenidæ. In the Eucreodi, including only the Eocene family of the Miacidæ, the specialized carnassial function was confined to the fourth upper premolar and the first lower molar exactly as in the modern Fissipedia. 'As regards the Eocene Carnivora,' he continues (page 320), 'it appears better to retain the generally accepted arrangement as more natural and convenient. They form a natural and readily definable suborder, divisible into three groups of about equal value, besides a few primitive forms of uncertain affinities. One of these groups gave rise to the Fissipedia by assumption of a number of progressive characters; the others became extinct without assuming these progressive characters. The conversion of the adaptive Creodonts into Fissipedia and disappearance of the inadaptive groups nearly coincide with the end of the Eocene. If on the other hand we place the Adaptive Creodonts in the Fissipedia, we not only remove them from their nearest relatives and make it difficult to adequately define the inadaptive groups so as to exclude them, but we obscure, as it seems to me, the real relationships of the Eocene Carnivora to each other and to adjoining orders, as well as to the more modernized group. The attempt to distribute the adaptive genera into the modern families is open to more serious objections, as even with a complete knowledge of the skeleton it is not always possible to be sure of their exact relationship to the living carnivora, and to associate the closely allied Eocene genera with the widely separated modern families to which they may be ancestral, not only obscures their real relations,

but makes their position dependent upon very transitory and uncertain theories of phylogeny.'

"As regards the origin of the Fissipedia, Matthew suggested in the same memoir (1915, page 351) that 'it appears probable that in the Miacinæ and Viverravinæ we have the beginning of the differentiation into Arctoid and Aeluroid carnivora. . . .'

"The phylogeny of the bears continued to offer difficulties at this time (page 351) but as the years passed and he saw more and more of both dogs and bears as well as of alleged intermediate genera, he became firmly convinced that the bears had been derived from dogs of some sort."

THE BEGINNING OF MULTIPLE FAUNAL HORIZONS

As recently summarized by Osborn in the Titanothere Monograph, Leidy, Marsh and Cope had distinguished a limited number of Tertiary faunal horizons, for example, treating the Bridger Eocene and the White River Oligocene as wholes. The first step towards splitting these horizons into lesser divisions or life zones was made by Hatcher in the White River Titanotherium beds into three levels; this was followed by Wortman in subdividing the White River Oligocene into many life zones. Osborn had attempted this in his first studies on the Bridger and Washakie in 1878; he was convinced that closer analysis of the Bridger faunas would lead to further subdivision; with the financial aid of the United States Geological Survey he accordingly directed Walter Granger to closely record the change in geologic conditions and the levels in which every genus and species were found. Matthew was rather skeptical about the outcome but joined with Granger in this fresh paleontologic and geologic survey which yielded the most brilliant and unexpected results. Gregory describes this work as follows:

"Accordingly, one of the most important sections of the Memoir on the Bridger Carnivora and Insectivora was that which dealt with the stratigraphy and faunal divisions of the Bridger formation. This extensive paleontological and geological survey was made for the United States Geological Survey during the season of 1902 and 1904 in determining faunal levels in the Bridger formation in connection with Professor Osborn's investigations on the phylogeny of the titanotheres. Granger and Matthew were able to establish the existence of five successive major faunal levels containing numerous subdivisions and recognizable at many different localities in the Bridger basin. On the basis of the faunal lists recording the precise level of each species Matthew distinguished the Lower from the Upper Bridger and was able in the case of a number of species to trace the changes in the premolar and molar teeth as one passed from the lower to higher levels. In short, this memoir abounds in important and far-reaching facts, analyses and conclusions."

EODELPHIS AND OTHER CRETACEOUS MAMMALS OF AMERICA AND ASIA

"Another group of primitive mammals to which Matthew made an outstanding contribution was that of the primitive polyprotodont marsupials. In his paper on 'A Marsupial from the Belly River Cretaceous. With Critical Observations upon the Affinities of the Cretaceous Mammals' (1916) he described the lower jaw and parts of a skull of a small mammal which had been found by Barnum Brown on Red Deer River, Alberta, embedded beneath a ceratopsian dinosaur skull in a formation of unquestionably Upper Cretaceous age. The presence of ancestral opossums in the Cretaceous went far to confirm the views of Huxley, Dollo and Bensley that this family was practically ancestral to the more specialized marsupials of Australia and South America; and at the same time it gave additional evidence in favor of Matthew's view of the early Holarctic or northern origin of many groups now confined to tropical or southern latitudes.

"In connection with South American palaeontology he described (1915, pages 429-433) a curious little lower jaw from the Lower Eocene Wasatch of Wyoming, which he referred to the notoungulate order of Entelonychia. He pointed out that the molar teeth of this form resembled those of the Patagonian *Notostylops* and related types in general pattern and in the possession of certain features peculiar to the notoungulates. He thought it improbable that these resemblances could be due to convergence and therefore regarded the new form *Arctostylops* as probably an aberrant offshoot from the northern ancestors of the extinct South American ungulates. It was therefore a matter of great interest that one of the Museum expeditions in Mongolia discovered there in a formation of possibly Paleocene age a diminutive lower jaw, together with the upper cheek teeth of a mammal of the notoungulate type, that closely resembled *Arctostylops*. Here then was direct evidence for the view so long advocated by Matthew upon other grounds, namely, that the peculiar extinct South American orders had sprung from some very early immigrant from northern North America, which in turn had been derived from North Asiatic ancestors."

FOSSIL PRIMATES, EOCENE LEMUROIDS AND EDENTATES OF AMERICA

"The Lower and Middle Eocene Primates of North America were revised by Matthew in 1915; he was able to revise, confirm and considerably extend the previous reviews by Osborn (1902) and by Wortman (1904), and to add several new species of notharctids and 'anaptomorphids.' He was also able to trace, more closely than had hitherto been done, the transformation of the very simple triangular and tritubercular upper molar of the older species of *Pelycodus*, through a series of successive horizons, into the quadrate and quadritubercular of *Notharctus*. The discovery of good skeletal material of *Notharctus* enabled him to refer it definitely to the suborder Lemuroidea, in spite of the fact that *Notharctus* itself never assumed the specialized dentition of the modern *Lemur*.

"Among the Eocene Tarsiidæ he gave an excellent key for the distinction of the various genera and species and a carefully corrected reconstruction of the famous skull called by Cope '*Anaptomorphus homunculus*.'

"The Edentates naturally received considerable attention from Matthew, who had occasion to study especially the ground sloths of the Cope Pampean collection, the edentates collected by Barnum Brown in Patagonia, and the Taeniodonts and Palaeanodonts of the Basal and Lower Eocene. 'The Ancestry of the Edentates' was treated in an illuminating way in a brief, semi-popular article in 1912, in which the mounted skeleton of *Hapalops*, an ancestor of the ground sloths from the Patagonian Miocene, was fully described. The Palaeanodonta were named by Matthew (in 1915) as a suborder of Edentata, to include the Metacheiromyidæ of Wortman, which were at first referred by the latter to the Cheiromyoid division of the Primates. *Metacheiromys* had been redescribed from better material by Osborn, who had referred to it as 'An Armadillo from the Middle Eocene (Bridger) of North America.' Matthew's *Palaeanodon ignavus* was based on a skull, vertebræ, foot-bones, etcetera, from the Lower Eocene (Wasatch) of Wyoming. This skeleton was shown to be closely related to the Bridger *Metacheiromys* but more primitive in several respects. A careful consideration of the characters and affinities of *Palaeanodon* and *Metacheiromys*, in comparison with armadillos and other Xenarthra, with *Manis* and *Orycteropus* and their supposed relatives in the Tertiary of Europe led Matthew to the conclusion (page 652) that *Palaeanodon* is related to the armadillos."

FOSSIL AND RECENT HOOFED MAMMALS, UNGULATES

"Dr. Matthew's contributions to knowledge of the fossil ungulates were numerous and fundamental. His early studies (1897, pages 299-311, 320, 321) on the skeleton of *Euprotogonia*, from the Torrejon, abound in observations of great interest and value. He remarked that 'in every detail of its skeletal structure this relatively primitive condylarth shows a most striking resemblance to the Creodonts. The customary bend of the knee and elbow, the long heavy tail, the semiplantigrade five-toed foot are general points of likeness, and when we compare the separate limb-bones, the close relationship becomes apparent, especially close to the primitive types. . . . In every point where *Euprotogonia* differs from *Phenacodus*, it approaches the Creodonts—or rather approaches that hypothetical form from which descended both Creodonts and Condylarths. It stands therefore in a strictly intermediate position. . . .' While Cope had supposed that the Lower Eocene *Phenacodus* was the 'five-toed ancestor of the horse,' Matthew concluded (page 309) that '*Euprotogonia* stands nearer to the early Horses than does *Phenacodus*, but I do not think that it can be considered the direct ancestor of *Hyracotherium*. . . .'

[The Matthew theory that the condylarth *Euprotogonia* was ancestral to the Perissodactyls including the stem form of the horses is not supported by Osborn.]

"In his 'Memoir on the Bridger Carnivora and Insectivora' (1909), already noted, Matthew gave a very full description of the skull and dentition of *Hyopsodus*. Earlier authors had classed these small animals with the Primates because of the general resemblance of their molar teeth to those of *Notharctus*. Wortman had removed them from the Primates to the Insectivora. Matthew

in 1909 allowed the family to remain in that order, although expressing the opinion (page 512) that 'its affinities are in reality closer to the Condylarthra than to the more typical Insectivora.' In 1915 (page 312) he states that 'additional skeletal material of *Hyopsodus*, including a well preserved hind foot, served to confirm the above somewhat tentative conclusion and made it advisable to remove the family to the Condylarthra.' "

In 1897 he began to treat the archaic ungulates and first followed Cope, referring them chiefly to the Condylarthra, but later he followed Osborn in referring the Periptychidæ and Pantolambdidæ to the Taligrada as a distinct early subdivision of the Amblypoda.

"In this recent paper (1928, page 968) he showed that so far as regards the patterns of the upper molar teeth, the Amblypoda included two very distinct divisions: the first comprising the Paleocene *Pantolambda*, the Lower Eocene *Coryphodon* and the Upper Eocene Mongolian *Eudinoceras*, the second including the Paleocene *Prodinoceras*, the Lower Eocene *Bathyopsis*, the Middle Eocene *Uintatherium* and the Upper Eocene *Eobasileus*. The discovery in Mongolia of *Prodinoceras* showed that the attempts to derive the *Uintatherium* type of molars from those of *Coryphodon* had been in vain and that the two divisions of the Amblypoda were already widely different from each other in the Paleocene.

"*Artiodactyls.* Matthew's contributions to the phylogeny of the Artiodactyla were many and varied, too much so, in fact, to be noticed in detail in this all too brief outline of his principal results. He dealt in numerous papers with the camels, oreodonts, hypertragulids, cervids, giraffes, antilocaprids, antelopes, cattle, etcetera, of the ruminant series as well as with the anthracotheres and dicotylids of the suillines. In his final diagram of the 'phylogeny of the Artiodactyla' his summary of the actual paleontological succession and of the relationships of the modern families to their Eocene and Paleocene forerunners are clearly set forth. In one of his later papers, published June 30, 1929, he gives an admirably clear and practicable 'Reclassification of the Artiodactyl Families' into five major groups, as follows: Palaeodonta, or primitive Bunodonts, including the American Eocene dichobunids and the Upper Eocene to Miocene Entelodonts; Hyodonta, or pig-like bunodonts, including the pigs, peccaries and hippopotami; Ancodonta, or primitive tetradactyl Selenodonts, a large group including the old bunoselenodonts, the Caenotheriidæ and Oreodontidæ, with the four-toed short feet of the pig group but partly or wholly selenodont molars; Tylopoda, or Camel group, including the Xiphodonts and Camels; Pecora, or true Ruminant group, including the tragulids, cervids, giraffids, antilocaprids and bovids.

"*The Horses.* As a result of systematic collecting continued year after year the American Museum of Natural History amassed an enormous collection of fossil Equidæ throughout the long series of Tertiary and Quaternary horizons. Matthew intensively studied thousands of teeth and skeletal parts of fossil Equidæ, not only while identifying and cataloguing the collections but especially in preparing his various faunal papers, including the 'Third Contribution to the Snake Creek Fauna' (1924). With reference to the collection of fossil

Equidæ from the Snake Creek quarries in Western Nebraska he wrote (op. cit., page 154): 'This represents many thousands of individuals, no two of them exactly alike in the complex details of tooth construction. If the standards of species distinction that have been accepted by most American students of fossil Equidæ were applied conscientiously to this great collection, the result would be to place upon record scores if not hundreds of 'new species' from this one locality. But the thousands of isolated teeth or other fragmentary specimens would clearly show that there are no really constant and uniformly associated distinctions between such 'species.' They are mainly individual differences. . . .' Again, in discussing the relationship of *Pliohippus* to *Equus* and *Hippidium*, he writes as follows:

"'I believe, however, that the hard and fast lines of distinction that it is customary among palaeontologists (and zoologists) to draw between 'species' are not justified by the evidence; that when one deals with very extensive series of specimens from many closely succeeding stages and many localities, the amount and character of intergrading and mixture of their species characteristics is only explicable as the result of continual admixture of numerous interbreeding strains, so that the 'species' is merely a more or less arbitrary selection of material representing approximations to a strain locally and temporarily dominant. It is to be pointed out in this connection that interbreeding does not produce exact intergradation in the characters of a series of specimens but various admixtures of more or less distinct and definite characters. . . . From this viewpoint the more detailed affinities of the later Equidæ are matters of degree of relationship or dominance of one or another ancestral stock in a complexity of intercrossing strains which only slowly and gradually take on that complete infertility between progressively diverging groups which brings about definite and permanent distinctness.' In his application of this theory to the origin of the modern *Equus*, he suggested (page 168) that '*Equus* shows an admixture, somewhat varying in its different species, of progressive characters, some of which are assumed earlier by typical *Pliohippi*, some by typical *Hipparions;* there is nothing in the generic characters of either genus to exclude it from the ancestry of *Equus* but all the better-known species of each are off the direct line, although some are perhaps not excluded from participation in some degree in the ancestry of the modern horses.'

"In view of all this it was a matter of considerable interest that soon afterward (1924) Dr. Matthew and his assistant Mr. George G. Simpson discovered in the Blanco (Middle Pliocene) formation of Texas two skeletons of a fossil equine which proved to be intermediate in character between *Pliohippus* and *Equus*. This stage of evolution was accordingly named by Matthew, *Plesippus* (near horse).

"As a result of his great mass of detailed knowledge of the fossil Equidæ, Matthew was able to prepare an excellent handbook on the Evolution of the Horse and an authoritative and critical review of the same subject, published in the *Quarterly Review of Biology*, 1926, with many beautiful illustrations and diagrams. The same article also contains his diagram showing the divergent evolution of the perissodactyls in the Older Tertiary, which summed up the

results, primarily of his own studies, but with due regard to the views of other authorities, on the phylogeny of the numerous families and subfamilies of rhinoceroses, lophiodonts, tapirs, horses and other perissodactyls."

[Matthew's views of the evolution of the Equidæ were throughout wholly different from those of Osborn; for a long time he was inclined to derive the true horse, *Equus,* from the Pliocene *Hipparion.* Later in advancing the hypothesis that *Equus* might have been derived from interbreeding between several Pliocene genera Matthew unconsciously revived the ancient theory of the rise of species by hybridization. Osborn's theory, on the contrary, holds to the absolute separation of all phyletic lines of descent, even back to very early times.]

THEORIES OF MAMMALIAN ORIGIN AND DISPERSAL

"In conclusion, we come to the more general theories of mammalian origin and dispersal for which Dr. Matthew was far more widely known than for his detailed technical monographs, although the latter must always be regarded by active students of fossil mammals as of far greater importance and value. The first was his theory of the arboreal origin of the Mammalia, which was set forth in a brief article in the *American Naturalist* in 1904. Here he noted that while Huxley, Dollo and Bensley had adduced strong evidence for the arboreal origin of the marsupials, he had for some time been of the opinion that this was true not only of the marsupials but of the placentals as well. In support of this view he cited various skeletal characters of the oldest oreodonts, protoungulates, rodents, primates, etcetera, which appeared consistent with the hypothesis that they were either semi-arboreal to arboreal or had been derived from arboreal Mesozoic mammals. He then reviewed the vertebrate faunæ and life zones of the later Mesozoic era, suggesting that while the giant reptiles for the most part held the terrestrial field, the mammals had remained as small forest-living, arboreal or semi-arboreal forms, but that with the great climatic changes at the close of the Mesozoic and the consequent spread of upland conditions, the mammals had abandoned their arboreal habitat and exploited the areas left more or less vacant by the giant reptiles. Against this theory Dr. Gidley later brought the objection that certain of the characters cited for arboreal ancestry by Matthew (such as the five-toed spreading hands and feet, long tail) might be merely primitive characters inherited from reptilian ancestors. But to the reviewer it seems that the resemblances of the Paleocene mammals to the reptiles are only very distant and general ones, while their resemblances to the arboreal opossum are much more specific, though their former arboreal adaptations even in the Paleocene, had already undergone considerable reduction in response to the various terrestrial adaptations which they were then assuming.

"By far the most famous of Matthew's works was his 'Climate and Evolution' (1915). His main theses were: (*a*) the relative permanency of the great ocean basins, as a result of isostatic relations of water and land masses; (*b*) the origin of most of the orders and families of mammals in Holarctic areas and the subsequent spreading of many of them into southern latitudes; (*c*)

the deployment in the southern countries of the descendants of immigrants from the north, into new fauna like those of the marsupials of Australia or the extinct notoungulates of South America; (*d*) the importance of geographic isolation in protecting the descendants of archaic stocks from the destructive competition of the higher placental orders; (*e*) the impelling force of secular climate changes, such as the great lowering of temperatures at the various periods from the Permian onward, in causing increased severity of Natural Selection for higher body temperatures, for larger and better brains and other superior adaptations against extremes of heat and cold.

"In connection with this general theory Matthew vigorously opposed the hypothetical building of great 'land bridges' across wide ocean spaces to account for similiarities between animals and plants on opposite shores of the oceans. He was able to adduce strong evidence, for example, that such forms as the extinct chrysochlorid-like *Necrolestes* of Patagonia and the true chrysochlorids of South Africa owed their resemblances not to direct relationship but to a common origin from northern stock of Paleocene or Eocene age. The peopling of oceanic islands with small mammals he attributed to chance transportation, as by natural rafts, hurricanes, etcetera, rather than to former connections with the mainland. In this connection one naturally recalls his carefully considered paleogeographic maps ('Hypothetical Outlines of the Continents in Tertiary Times,' 1906) and polar projections, which greatly assist in the visualization of his views on the migrations of mammals.

"In conclusion, Matthew's many close friends, colleagues and students, while mourning over his quite untimely decease, are at the same time conscious of the immense benefits to biological science that must continue to result from his highly effective labors. In many fields he set masses of confused data in order, leaving a secure basis for further progress. And in the last few years of his life he started a great movement for the breeding and training of new explorers in these fields, a movement to which his colleagues and students will undoubtedly impart a steady acceleration and widening during the years to come."

SUMMARY OF MATTHEW'S CONTRIBUTIONS TO VERTEBRATE PALEONTOLOGY

In the revised bibliography appended to this Memoir, including 257 titles, Matthew's fellow geologists and paleontologists will be amazed at the extraordinarily wide scope both of his serious investigations and of his speculative writings. These were partly the result of his own very broad and philosophical point of view, of the marked originality of his ways of thinking, also of the unique opportunities afforded by thirty years in the service of the American Museum of Natural History with its far-flung expeditions and rare opportunities of personal contact and discussion with workers in other fields. Rapidly incoming collections from different parts of the earth one by one led him to study the Tertiary and Quaternary faunas of North and South America, of Europe, of India, Burma, Java and Mongolia from two points of view—first, as

curator-in-chief of these collections from the year 1908 onwards; second, in philosophical generalization as a geologist and geographer on problems of faunas, of migrations, and of continental connections.

The enforced precision of his work as a cataloguer would have swamped a lesser man and made him a mere species maker, but Matthew, in co-operation with the field workers, Wortman, Petersen, and Granger, used his own very precise observations for larger generalizations for determining the precise limitation of horizons, and ultimately aided by Osborn in comparing these American horizons with similar contemporaneous horizons in very remote parts of the world.

His opinions and theories throughout were individualistic and he was inclined to hold to them tenaciously, modifying them only slightly in advancing years. The opinions and theories of his colleagues in successive years, Wortman, Gregory, Osborn, had little weight with him. In fact, he showed a tendency to react in an opposite direction, especially from the opinions and theories of Osborn, although these intellectual differences were never allowed to affect personal relations.

For example, Matthew was inclined to hold Cope's views of horizontal classification and never was disposed to adopt Osborn's newer phylogenetic classification. He also held Cope's views as to the origin of the higher orders of Lower, Middle and Upper Eocene mammals by direct descent from the lower orders of archaic mammals of Paleocene time; in this Matthew's views were partly or largely shared by Gregory. Osborn, on the other hand, set the known archaic Paleocene mammals apart in a great separate division of Meseutheria, characterized by small brains and mechanically imperfect feet. Again, Matthew inclined toward entirely individual opinions not only as to the continuity of distinct phyla but as to the origin of species and genera, as shown in his remarks quoted above from Gregory on the origin of the modern horse, *Equus*. Many other examples might be cited of profound differences of opinion and of theory which separated Matthew not only from Osborn but from many other colleagues.

This characteristic of independent thought is not mentioned here for purposes of discussion, but simply to point out the independent and often daring temper of Matthew's mind. It was this independence that led to some of his most novel and important generalizations, especially to his very largely original "North Polar or Holarctic theory" of the origin of all the mammals without the aid or intervention either of transoceanic land bridges in the northern hemisphere or in the southern. Thus, in his brilliant and strongly sustained argument for northern dispersal, he

dismissed as untenable all the arguments which had previously been advanced by Osborn and others for connections between the Antarctic Continent, Australia and South America.

Matthew's development of the North Polar theory is admirably summarized by Gregory as follows:

"Another instance of his conservative progressiveness may be found in his most widely known work, 'Climate and Evolution' (1915). Being a student of Alfred Russell Wallace's works on geographic distribution, he sided with that great naturalist in opposing those who lighly reconstructed 'land-bridges' across the oceans of any and every geologic epoch in order to account for the presence of related animals and plants on opposite shores of ocean barriers. From his vast and intimate knowledge of the fossil record of the vertebrates, he was able to show that many groups whose representatives are now found dispersed in far distant tropical and southern continents are the specialized descendants of known fossil types which in the Eocene and later epochs were inhabitants of the northern lands. His excellent distribution maps were 'North Polar projections' of the continental land masses, upon which was plotted first, the distribution of the Eocene and later ancestors of the horses, tapirs, rhinoceroses, camels, pigs, ruminants, dogs, cats, etcetera, which were all known only in the northern hemisphere; second, the present distribution of the scattered representatives of many of these families in tropical and southern land masses. His inference was that these forms had originated in the northern hemisphere, had then spread southward into the tropical and southern countries, while the original stock often became extinct in the northern homeland.

"On the geologic side he adopted the theory of isostasy, in so far as it was developed at the time. According to this theory, the continents and oceans are held in balance in such a way that only minor oscillations of level have occurred; thus, although the land was at intervals submerged under shallow invasions of the sea, while at other times the continents emerged to higher levels, yet the main continental masses have remained substantially intact, at least throughout the period covered by the records of vertebrate life. In order to account for the first colonization by mammals of continental islands, including Madagascar, Australia, New Zealand, be followed Wallace in evoking the agency of those 'natural rafts,' which emerge in great numbers from continental rivers and carry sometimes a stray small mammal. Once in a million or more chances, he argued, this castaway might be a gravid female whose progeny could subsequently colonize the whole island. He cited the evidence that tended to support the view that even the most gigantic Australian marsupials had been derived eventually from small arboreal ancestors, which were the only kind that might be conceived to be capable of living in a tangled mass of vegetation during its long drift across the sea and through subsequent perils of landing on a strange shore.

"Thus Matthew came to deny the validity not only of all the supposed sunken 'land-bridges' across the Atlantic and Pacific which had been evoked by various authors, but also the supposed former connections of South Africa, Aus-

tralia and South America with the Antarctic continent. Accordingly he ascribed to 'parallelism' the rather striking resemblances of the extinct 'Sparassodonts' of Patagonia with the existing thylacine marsupial wolves of Tasmania."[9]

SAD CLOSE OF A GREAT CAREER

Up to the year 1927, Matthew's achievements were all in the field of exploration and research rather than of education. In this field his training was chiefly that of a writer and speaker with unusual powers of popular exposition and great personal charm because of the original and independent currents of thought lightened by occasional flashes of wit and humor and deepened by his underlying and enthusiastic interest in every subject on which he undertook to speak or to write.

While his colleagues and associates of thirty-two years in the American Museum of Natural History were deeply regretful to have him sever his long and brilliant connection with the American Museum they all felt that in his call to the University of California, as professor of paleontology and curator of the Paleontological Museum, there opened before him a new and great opportunity to impart his knowledge to new and eager groups of students and thereby continue and strengthen the work so ably begun by his distinguished predecessor, Professor John C. Merriam, who left California to become the head of the Carnegie Institution of Washington.

The hopes of Matthew's friends for his success in this new line of scientific endeavor were fully realized. He not only aroused the interest and attention of very large classes of students but he attracted to the none too crowded professional ranks of vertebrate paleontology a number of very promising neophytes.

Of his life at the University of California, three of his colleagues, C. L. Camp, R. W. Chaney and S. J. Holmes, wrote as follows:

"At the University of California Dr. Matthew, in three years, built up a comprehensive plan for the development of the Department and Museum of of Paleontology. He brought to his teaching the ripe experience of years of research and to his Museum the record of a great achievement in the organization of a similar institution in New York.

"His last researches were devoted to a new fauna from the Pliocene of Texas, which the University has been collecting.

"Professor Matthew has contributed to the advancement of paleontology not only by his numerous papers and his untiring efforts in building up the collections of the American Museum of Natural History and, later, in our own Museum of Paleontology, but also through his stimulating influence upon fel-

[9] William King Gregory: William Diller Matthew, Paleontologist (1871-1930). Science, December 26, 1930, vol. lxxii, no. 1878, pp. 642-645.

low workers who have had the good fortune to be associated with him. His wide knowledge, his sound critical judgment, his contagious enthusiasm, and his readiness to give assistance to his co-workers and students have won him the gratitude of many workers who have profited by his encouragement and counsel.

"There are certain qualities of mind and character which one naturally associates with the ideal man of science. Professor Matthew possessed these qualities to an unusual degree, combining the traits of a highly trained and critical investigator with the patience, helpfulness, and kindly attitude which won for him the admiration and affection of all who came really to know the man. His stay with us was short, but his influence will long remain. While we deeply deplore his passing, we feel that the University gained much from his presence, and that it may always look back with pride at having him among the members of its staff."

It is for these reasons that we feel that Dr. Matthew's loss is irreparable; he was cut off at a moment when his knowledge of the fossil mammalia of the world was unparalleled and when much of this knowledge was still awaiting publication; he was cut off when he was just entering the full tide of a new life as a teacher and educator.

His engagements as professor in the University of California admitted of his returning during three of the summer months to his old room in the American Museum to complete his final memoir on the Paleocene mammalia. He returned in July, 1930, apparently in good health and full of zest for his renewal acquaintance with the fossil specimens to which he had devoted his life, but with the added and delightful anticipation of a family reunion to celebrate the twenty-fifth anniversary of his marriage to Miss Kate Lee on July 15, 1905. Dr. and Mrs. Matthew, accompanied by their two daughters and son, came East full of hope and happy anticipation. There was a glad welcome at the American Museum. His friends had not heard of certain serious symptoms which had developed in May. These symptoms recurred and a New York physician advised immediate return to California. Again he showed his wonderful fortitude and loveliness of character during a succession of operations of most grave nature and an illness of four months. Finally on September 24, 1930, he passed away at the age of fifty-nine. To the last he was sustained by the devoted care of his wife and aided by a loving group of his California colleagues who had been buoyed by the hope that his vigorous constitution would enable him to recover.

The personal as well as scientific tributes from older and younger friends which are quoted in this Memoir, and the thought of a blameless and wonderfully creative and productive life afford our chief consolation in this most untimely and irreparable loss.

Bibliography

Titles of 1892 to 1921 inclusive were arranged by Dr. Matthew personally, with the insertion of twenty-six titles which he had omitted. Bibliography of 1922 to 1930 was arranged from a complete set of his writings in the Osborn Library of the American Museum of Natural History. Entire series of papers, 1-257, are numbered chronologically from the beginning so that authors may refer to this bibliography without citing titles in full. For example, 1892.7, 1893.4.

1892

1. Topaz from Japan. School of Mines Quarterly, number 1, volume XIV, pages 53-56.

1893

2. On phosphate nodules from the Cambrian of southern New Brunswick. Transactions of the New York Academy of Sciences, volume XII, pages 108-120.
3. On antennæ and other appendages of *Triarthrus beckii*. American Journal of Science and Art, series 3, volume XLVI, pages 121-125; Transactions of the New York Academy of Sciences, volume XII, pages 237-241.
4. A study of the scale characters of the northeastern American species of Cuscuta. Bulletin of the Torrey Botanical Club, volume XX, number 8, pages 310-314.

1894

5. The intrusive rocks near St. John, New Brunswick. Transactions of the New York Academy of Sciences, volume XIII, pages 185-203.
6. The crystalline rocks near St. John, New Brunswick, Canada. (Read May, 1894.) Bulletin of the Natural History Society, New Brunswick, volume XII. [Includes a brief sketch of the principles of metamorphism and igneous intrusions.]

1895

7. Monazite and orthoclase from South Lyme, Connecticut. School of Mines Quarterly, volume XVI, number 3, pages 231-233.
8. The effusive and dyke rocks near St. John, New Brunswick. Transactions of the New York Academy of Sciences, volume XIV, pages 187-217.
9. The volcanic rocks of the Maritime Provinces of Canada. (Read May 7, 1895.) Bulletin of the Natural History Society, New Brunswick, volume XIII.

1897

10. Status of the Puerco fauna. (Abstract.) Anat. Anz., volume XIV, pages 231, 232.
11. Status of the Puerco fauna. Transactions of the New York Academy of Sciences, volume XVI, pages 369, 370.
12. Development of the foot in Palæosyopinæ. American Naturalist, volume XXXI, pages 57-58.
13. Notes on intrusive rocks near St. John, New Brunswick, Canada. (Read May 4, 1897.) Bulletin of the Natural History Society, New Brunswick, volume XV.

14. A revision of the Puerco fauna. Bulletin of the American Museum of Natural History, volume IX, article xxii, pages 259-323, 20 text figures. [Revision of the species and their affinities, based on a restudy of the Cope Collection along with American Museum collections made in 1892 and 1896. Torrejon and Puerco faunas distinguished. Cope's theory of primitive serial carpus and tarsus rejected.]

1898

15. Clænodon and Oxyæna described. (Abstract.) Science (2), volume VIII, page 880.

1899

16. A provisional classification of the fresh-water Tertiary of the West. Bulletin of the American Museum of Natural History, volume XII, pages 19-75. [Revised list of mammal faunæ of American Tertiary formations with details of occurrence and critical estimate of the validity and importance of species. Correlation based upon these data.]
17. Is the White River Tertiary an æolian formation? American Naturalist, volume XXXIII, number 389, pages 403-408.
18. The ancestry of certain members of the Canidæ, the Viverridæ and Procyonidæ. (With J. L. Wortman.) Bulletin of the American Museum of Natural History, volume XII, pages 109-139, plate vi and 10 text figures. [The sections by Matthew deal with the affinities of the Oligocene ("Miocene") Canidæ of North America, and describe Phlaocyon as an ancestor of the raccoons.]

1900

19. The Cope Pampean collection. American Museum Journal, volume I, number 2, pages 24-26.

1901

20. Additional observations on the Creodonta. Bulletin of the American Museum of Natural History, volume XIV, pages 1-38, 17 text figures. [Classification of the Creodonta, with brief discussion of principles. New observations upon various Creodont genera.]
21. Fossil mammals of the Tertiary of northeastern Colorado. Memoirs of the American Museum of Natural History, volume I, pages 353-446, plate xxxvii-xxxix, 34 text figures. [Lacustrine origin of White River and Loup Fork groups rejected in favor of flood-plain playa and æolian deposition. New theory of adaptation of sabre-tooth cats. Description of new collections obtained in 1898, and revision of various groups, Carnivora, camels, oreodonts, etcetera.]

1902

22. The hall of vertebrates. Supplement, American Museum Journal, volume II, number 1, pages 1-19.
23. A skull of Dinocyon from the Miocene of Texas. Bulletin of the American Museum of Natural History, volume XVI, article xi, pages 129-136.
24. On the skull of Bunælurus, a Musteline from the White River Oligocene. Bulletin of the American Museum of Natural History, volume XVI, article xii, pages 137-140.

25. [Note on the exhibit, development of the horse.] American Museum Journal, volume II, number 5, pages 40-41. (Unsigned.)
26. New Canidæ from the Miocene of Colorado. Bulletin of the American Museum of Natural History, volume XVI, article xxi, pages 281-290. [First outline of theory of Holarctic dispersal and climatic control. (Pages 286-287).]
27. A horned rodent from the Colorado Miocene. With a revision of the Mylagauli, beavers and hares of the American Tertiary. Bulletin of the American Museum of Natural History, volume XVI, article xxii, pages 291-310. [Description of Ceratogaulus. Affinities of Mylagaulidæ, Steneofiber and Palæolagus.]
28. The skull of Hypisodus, the smallest of the Artiodactyla, with a revision of the Hypertragulidæ. Bulletin of the American Museum of Natural History, volume XVI, article xxiii, pages 311-316. [Revision and affinities of Hypertragulidæ.]
29. List of the Pleistocene fauna from Hay Springs, Nebraska. Bulletin of the American Museum of Natural History, volume XVI, article xxiv, pages 317-322.

1903

30. The evolution of the horse. American Museum Journal, volume III, supplement, January, 1903. 30 pages, 6 plates, 5 text figures. Second edition issued May, 1905. Guide Leaflet number 9. [A popular guide to the American Museum collection of fossil Equidæ, pointing out the mechanics of the adaptive changes, and the environmental and climatic changes that brought them about.]
31. Second Cope collection and Pampean collection. American Museum Journal, volume III, number 1, pages 3-6.
32. News notes. (Unsigned.) Idem, volume III, number 4, pages 58-61.
33. The collection of fossil vertebrates. Idem, volume III, number 5, supplement, pages 1-32. Guide Leaflet number 12.
34. The fauna of the Titanotherium Beds of Pipestone Springs, Montana. Bulletin of the American Museum of Natural History, volume XIX, pages 197-226, 19 text figures. [Various new Lower Oligocene genera described and affinities discussed.]
35. A fossil hedgehog from the American Oligocene. Idem, volume XIX, article vii, pages 227-229.
36. Recent zoöpalæontology (concerning the ancestry of the dogs). Science, new series, volume XVIII, pages 912-913.
37. [Exhibition of a series of foot-bones showing the evolution of the camel.] Idem, volume XIX, page 992.

1904

38. The arboreal ancestry of the Mammalia. American Naturalist, volume XXXVIII, pages 811-818.
39. An extinct cave fauna in Arkansas. American Museum Journal, volume IV, number 1, pages 6-7.

40. Department of Vertebrate Palæontology. Field explorations in 1903. American Museum Journal, volume IV, number 1, pages 14-15.
41. Eocene fossil mammals of South America. American Museum Journal, volume IV, number 1, page 26.
42. Notice of two new Oligocene camels. Bulletin of the American Museum of Natural History, volume XX, article xvii, pages 211-215.
43. A complete skeleton of Merycodus. Bulletin of the American Museum of Natural History, volume XX, pages 101-130, plate iii, and 18 text figures. [Description of complete skeleton. Related to Antilocapra.]
44. Outlines of the continents in Tertiary times. Science, new series, volume XIX, pages 581-582.
45. New or little-known mammals from the Miocene of South Dakota. American Museum of Expedition of 1903. By W. D. Matthew and J. W. Gidley. Part II. Carnivora and Rodentia by W. D. Matthew. Bulletin of the American Museum of Natural History, volume XX, pages 241-271.
46. Mode of evolution of the Vertebrata. In International Encyclopœdia, article Vertebrata.

1905

47. Fossil carnivores, marsupials and small mammals in the American Museum of Natural History. American Museum Journal, volume V, number 1. Guide Leaflet number 17.
48. The mounted skeleton of Brontosaurus in the American Museum of Natural History. American Museum Journal, volume V, number 2.
49. Notice of two new genera of mammals from the Oligocene of South Dakota. Bulletin of the American Museum of Natural History, volume XXI, article iii, pages 21-26.
50. On Eocene Insectivora, and Pantolestes in particular. Science, new series, volume XXI, number 530, pages 298-299.
51. Notes on the osteology of Sinopa, a primitive member of the Hyænodontidæ. Proceedings of the American Philosophical Society, volume XLIX, pages 69-72.

1906

52. The osteology of Sinopa, a creodont mammal of the Middle Eocene. Proceedings of the United States National Museum, volume XXX, pages 203-233, plate xvi and 20 text figures. [Description of a complete skeleton in the National Museum; affinities of Sinopa, revision of the species.]
53. Field work of the Department of Vertebrate Palæontology. American Museum Journal, volume VI, number 3, pages 122-123.
54. Hypothetical outlines of the continents in Tertiary times. Bulletin of the American Museum of Natural History, volume XXII, pages 353-384, 7 text figures. [Contains a series of maps attempting to correlate views of various authorities on a somewhat conservative basis. The antarctic connections shown in one of these maps were shortly afterwards abandoned as untenable.]
55. Fossil Chrysochloridæ in North America. Science, new series, volume XXIV, pages 786-788.

1907

56. The skeleton of the Columbian mammoth. American Museum Journal, volume VII, number 1, pages 5-6. (Unsigned and of doubtful authorship.)
57. Department of Vertebrate Palæontology. Field expeditions of 1906. Idem, pages 6-8. (Unsigned.)
58. The Naosaurus or "ship-lizard." Idem, volume VII, pages 36-41.
59. A Lower Miocene fauna from South Dakota. Bulletin of the American Museum of Natural History, volume XXIII, pages 169-220, 26 text figures. [First discovery of the true Lower Miocene fauna; discussion of correlation and affinities.]
60. The relationships of the Sparassodonta. Geological Magazine, new series, volume IV, pages 431-535.

1908

61. Mammalian migrations between Europe and North America. American Journal of Science, volume XXV, pages 68-70.
62. Allosaurus, a carnivorous dinosaur, and its prey. American Museum Journal, volume VIII, number 1, pages 1-5.
63. The new Ichthyosaurus. Idem, volume VIII, number 1, pages 6-8.
64. News notes. The Trachodon group. (Unsigned.) American Museum Journal, volume VIII, page 89.
65. News notes. Additions to the hall of fossil mammals. (Unsigned.) American Museum Journal, volume VIII, page 89.
66. Review of "A Revision of the Pelycosauria of North America," by E. C. Case. Science, new series, volume XXVII, pages 816-818.
67. A four-horned Pelycosaurian from the Permian of Texas. Bulletin of the American Museum of Natural History, volume XXIV, article xi, pages 183-185.
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69. Exhibit illustrating the evolution of the horse. American Museum Journal, volume VIII, number 8, pages 117-122.

1909

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74. The Carnivora and Insectivora of the Bridger Basin, Middle Eocene. Memoirs of the American Museum of Natural History, volume IX, part vi, pages 291-567, plates xlii-li, 118 text figures. [Review of the Bridger formation, the source and method of deposition of the sediments, stratigraphic and faunal division; adaptation and ecology of the fauna. Detailed osteological descriptions of Bridger Carnivora and Insectivora, discussion of affinities and classification; various new or little known types fully described.]
75. A Pliocene fauna from western Nebraska (with H. J. Cook). Bulletin of the American Museum of Natural History, volume XXVI, pages 361-415, 27 text figures. [First description of the Snake Creek fauna, regarded as Lower Pliocene.]
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1910

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80. Patagonia and the Pampas Cenozoic of South America. A critical review of the correlations of Santiago Roth, 1908. Annals of the New York Academy of Sciences, volume XIX, number 7, part ii, pages 149-160.
81. On the skull of Apternodus and the skeleton of a new Artiodactyl. Bulletin of the American Museum of Natural History, volume XXVIII, article v, pages 33-42.
82. On the osteology and relationships of Paramys and the affinities of the Ischyromyidæ. Idem, volume XXVIII, pages 43-72, 19 text figures. [Complete skeletons of Eocene rodent Paramys, and skulls, etcetera, of other Eocene and Oligocene Rodentia described. The Eocene Ischyromyidæ regarded as the primitive group from which the other rodent groups, all of later age, have been diversely specialized.]
83. The phylogeny of the Felidæ. Idem, volume XXVIII, pages 289-316, 15 text figures. [The Tertiary Felidæ regarded as representing two phyla, one leading from Dinictis up into the true cats, the other from Hoplophoneus into the sabre-tooth tigers. Nothing is known of their Eocene ancestry. Discussion of the adaption of the sabre-tooths as shown by characters of skull and skeleton.]
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85. The pose of Sauropodous dinosaurs. American Naturalist, volume XLIV, pages 547-560.
86. Notes and literature—Schlosser on Fayûm mammals. American Naturalist, volume XLIV, pages 700-703.

87. Continuity of development. Popular Science Monthly, volume LXXII, pages 473-478. November, 1910. [Contribution to a symposium of the Paleontological Society, dealing with the question of saltation versus continuous progression in phylogeny of fossil vertebrates. The conclusion is reached that the apparently sudden appearance of new types is usually due to migration or to gaps in the geologic record, the best known phyla progressing through very small changes. This is in no wise held to exclude the mendelian character of such differences, but they are not normally large in amount.]

1911

88. The Fort Lee dinosaur. American Museum Journal, volume XI, number 1, pages 28-29.
89. The ground sloth group. Idem, volume XI, number 4, pages 113-119.
90. A tree climbing ruminant. Idem, volume XI, number 5, pages 162-163.
91. The amphibians of the great coal swamps. Idem, volume XI, number 6, pages 197-200.
92. Fossil vertebrates. What they teach. Idem, volume XI, number 7, pages 246-247.
93. News notes. Eocene fossil mammals. (Unsigned.) Idem, volume XI, number 8, page 311.
94. Review: "The origin and antiquity of man," by G. F. Wright. Current Anthropological Literature, volume I, number 4, pages 267-272.

1912

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96. Florentino Ameghino. Popular Science Monthly, March.
97. News notes. New exhibits of fossil vertebrates. (Unsigned.) American Museum Journal, volume XII, number 1, page 37.
98. News notes. Prjevalsky wild horses. Idem, volume XII, number 2, page 76.
99. The new four-toed horse skeleton. Idem, volume XII, number 5, page 186.
100. New dinosaurs for the American Museum. Idem, volume XII, number 6, page 219.
101. Facts and theories relating to the ancestry of man. Idem, volume XII, number 7, pages 255-256.
102. News notes. Fossil walrus skull from Penobscot Bay. (Unsigned.) Idem, volume XII, number 7, page 268.
103. The ancestry of the Edentates. Idem, volume XII, number 8, pages 300-303.
104. African mammals. Bulletin of the Geological Society of America, volume 23, pages 156-162.
105. Carnivora and Rodentia. Idem, volume 23, pages 181-187. [Critical reviews of the status of paleontology in these two fields.]

1913

106. News notes. A tiny fossil skull. (Unsigned.) American Museum Journal, volume XIII, number 1, page 48.

107. News notes. Dinosaur explorations in German East Africa. Idem, volume XIII, number 5, page 200.
108. American Museum expeditions for fossil vertebrates. Idem, volume XIII, number 6, pages 286-287.
109. The asphalt group of fossil skeletons. Idem, volume XIII, number 7, pages 291-297.
110. News notes. Exhibit of fossil rhinoceroses. (Unsigned.) Idem, volume XIII, number 7, page 374.
111. The laws of nomenclature in paleontology. Science, new series, volume XXXVII, number 960, pages 788-792.
112. Nomenclature in paleontology. Science, volume XXXVIII, pages 87-88, July 18, 1913.
113. The evolution of the horse. Revised and extended edition (with S. H. Chubb). Illustrations mostly new, text revised. Number 36 of the American Museum Guide Leaflet series.
114. A Zalambdodont insectivore from the basal Eocene. Bulletin of the American Museum of Natural History, volume XXXII, article xvii, pages 307-314, plates lx, lxi.
115. Certain theoretical considerations affecting phylogeny and correlation. Bulletin of the Geological Society of America, volume 24, pages 283-292.
116. Report of the Department of Vertebrate Paleontology. Annual Report of the American Museum of Natural History, volume XLV, pages 57-59.
117. New discoveries in the American Eocene. Report of the British Association for the Advancement of Science, volume LXXXIII, page 491.

1914

118. News notes. Fossils from Rancho-la-Brea. (Unsigned.) American Museum Journal, volume XIV, number 1, page 46.
119. News notes. New South American fossils. (Unsigned.) Idem, volume XIV, number 1, page 47.
120. News notes. Two new fossil mammals of the Lower Eocene. (Unsigned.) Idem, volume XIV, number 4, pages 167-168.
121. News notes. Expeditions for fossil vertebrates. (Unsigned.) Idem, volume XIV, number 5, page 214.
122. News notes. Discovery of Moropus skeletons. (Unsigned.) Idem, volume XIV, numbers 6-7, page 269.
123. The largest known dinosaur. A huge extinct reptile from German East Africa, the largest known quadruped. Scientific American, volume CXI, number 22, pages 443-446.
124. Evidence of the Paleocene vertebrate fauna on the Cretaceous-Tertiary problem. Bulletin of the Geological Society of America, volume 25, pages 381-402, September 15, 1914. [Characters of the Paleocene faunæ (Puerco, Torrejon, etcetera), comparison with Cretaceous faunæ and with true Eocene faunæ, correlations and interpretation. Faunal migrations are due to widespread diastrophic movements accompanied by climatic changes, and constitute the best practical evidence of such wide-

spread movements. The most marked faunal break is between the Paleocene and Eocene; between the Lance and Belly River there is a very considerable time interval, but no such marked faunal break as should indicate a change in period. Between Lance and Paleocene there is an apparent faunal break but it is of doubtful interpretation. But until these doubtful points are cleared up it seems better to retain the division at this point which is the classical and generally accepted line between Cretaceous and Tertiary.]

125. Time ratios in the evolution of mammalian phyla. A contribution to the problem of the age of the earth. Science, new series, volume XL, number 1024, pages 232-235.
126. Origin of Argentine wild horses. Nature, February 12, page 661.
127. Introductory note to A. Johannsen's "Petrographic analysis of the Bridger, Washakie and other Eocene formations of the Rocky Mountains." Bulletin of the American Museum of Natural History, volume XXXIII, article xvi, pages 209, 210.
128. New discoveries in the Lower Eocene mammals. (Abstract.) Annals of the New York Academy of Sciences, volume XXIX, page 383.
129. Discussion of C. Stock's paper on "The systematic position of the mylodont sloths from Rancho la Brea." Bulletin of the Geological Society of America, volume 25, page 144.
130. Report of progress in the revision of the Lower Eocene faunas. Bulletin of the Geological Society of America, volume 25, pages 144, 145.

1915

131. News notes. New exhibits of fossil vertebrates. (Unsigned.) American Museum Journal, volume XV, number 1, page 32.
132. News notes. New exhibits of fossil mammals. (Unsigned.) Idem, volume XV, number 2, page 86.
133. Ground sloth from a cave in Patagonia. Idem, volume XV, number 5, page 256.
134. News notes. Richard Lydekker, obituary notice. (Unsigned.) Idem, volume XV, number 5, page 263.
135. News notes. The Fulton mastodon. (Unsigned.) Idem, volume XV, number 7, page 373.
136. News notes. Fossil Sirenian from Porto Rico. (Unsigned.) Idem, volume XV, number 8, page 432.
137. Mammoths and mastodons. A guide to the collections of fossil Proboscideans in the American Museum of Natural History. Guide Leaflet series, number 43.
138. Climate and evolution. Annals of the New York Academy of Sciences, volume XXIV, pages 171-318, 33 text figures. [The geologic record shows a series of alternating stages of overflow and emergence of the continental platforms accompanied by cyclic changes in climate. The evolution and dispersal of animals and plants is interpreted as conditioned chiefly by these climatic and geographic changes. Owing to the relations of the continents this has involved a dispersal from the north-

ern Holarctic regions as the most prominent feature; but minor dispersal centers have been set up in the southern continents during their isolation. The deep ocean basins are regarded as permanent, at least during the later ages of geologic time; and the faunas of islands lying beyond the continental shelf are derived, with a few doubtful exceptions, by colonizations through accidental transportation by storms, "natural rafts," etcetera, not by former land connection. The evolution and dispersal of various groups of mammals and of lower vertebrates is traced in accordance with the principles outlined, through their successive stages, especially during the Tertiary and Pleistocene, and illustrated by a series of distribution maps, mostly based upon the north polar projection, which affords a more correct view of the true relations of the continents than does the usual Mercator's projection. The distribution of invertebrates and plants is believed to conform to these views if interpreted in accord with the principles here outlined.]

139. Dinosaurs. American Museum Handbook series, number 5, pages 1-162, 48 text figures. [A semipopular review of the various kinds of dinosaurs, their antiquity, habits and environment, based chiefly upon American Museum collections.]

140. A revision of the Lower Eocene Wasatch and Wind River faunas. By W. D. Matthew and Walter Granger. Part I—Order Feræ (Carnivora), suborder Creodonta. By W. D. Matthew. Bulletin of the American Museum of Natural History, volume XXXIV, article i, pages 1-103.

141. A revision of the Lower Eocene Wasatch and Wind River faunas. By W. D. Matthew and Walter Granzer. Part II—Order Condylarthra, family Hyopsodontidæ. By W. D. Matthew. Idem, volume XXXIV, article ix, pages 311-328.

142. A revision of the Lower Eocene Wasatch and Wind River Faunas. By W. D. Matthew and Walter Granger. Part IV—Entelonychia, Primates, Insectivora (part). By W. D. Matthew. Idem, volume XXXIV, article xiv, pages 429-483. [This revision is based upon the extensive collections and exact stratigraphic work of the American Museum expeditions of 1905, 1909-1916. Numerous new or little-known mammals are described, and the affinities of all the Lower Eocene genera and species discussed; the phyletic and faunal changes and the successive levels in the Lower Eocene formations and their correlation fully shown. Part III by Granger covers the remaining Condylarthra; part V is listed under the year 1918; part VI, Tillodonta and Tæniodonta by Granger; part VII, Amblypoda by Granger; part VIII, Perissodactyla by Granger, and part IX, conclusions, tabulation and correlation of faunas by Matthew and Granger, not yet published.]

143. Problems of American geology. Chapter VII. The Tertiary sedimentary record and its problems. Pages 377-478, map and 40 text figures, Yale University Press, 1915. [Discussion of the Tertiary sedimentary formations of the Cordilleran region, their character and origin. Review of the fossil record as contained therein showing the evolution of the Tertiary faunas.]

144. Reconstruction of the skeleton of Brachiosaurus. (Abstract.) Bulletin of the Geological Society of America, volume 26, page 153.
145. Hitherto unpublished plates of Tertiary Mammalia and Permian Vertebrata. American Museum of Natural History—the United States Geological Survey (with E. D. Cope).
146. Peccaries of the Pleistocene of New York (with John M. Clarke). Bulletin of the Geological Society of America, volume 26, pages 150, 151.
147. Megalocnus and other Cuban ground sloths (with Cralos de la Torre). (Abstract.) Bulletin of the Geological Society of America, volume 26, page 152.
148. Affinities of Hyopsodus. (Abstract.) Bulletin of the Geological Society of America, volume 26, page 152.
149. Corythosaurus, the new duck-billed dinosaur (with Barnum Brown). American Museum Journal, volume XV, number 8, pages 427-428.

1916

150. The grim wolf of the tar pits. American Museum Journal, volume XVI, number 1, pages 45-47.
151. News notes. Dinosaurs from Alberta. (Unsigned.) Idem, volume XVI, number 1, pages 74-75.
152. News notes. Fossil reptile exhibits—Myotragus—Antillean fossils. (Unsigned.) Idem, volume XVI, number 2, page 139.
153. News notes. Charles Falkenbach, obituary notice. (Unsigned.) Idem, volume XVI, number 3, page 209.
154. News notes. Expeditions for fossil vertebrates. (Unsigned.) Idem, volume XVI, number 3, page 209.
155. A reptilian Aëronaut. Idem, volume XVI, number 4, pages 251-252.
156. News notes. Expeditions for fossil vertebrates. (Unsigned.) Idem, volume XVI, number 6, page 412.
157. Scourge of the Santa Monica Mountains. Idem, volume XVI, number 7, pages 469-472.
158. The horse and his progenitors. Science Conspectus, volume VI, pages 1-15.
159. The origin of the Pacific faunas. Science, new series, volume XLIII, number 1115.
160. A new Sirenian from the Tertiary of Porto Rico, West Indies. Annals of the New York Academy of Sciences, volume XXVII, pages 23-29.
161. A Marsupial from the Belly River Cretaceous. With critical observations upon the affinities of the Cretaceous mammals. Bulletin of the American Museum of Natural History, volume XXXV, pages 477-500, plates ii-vi and 4 text figures. [Description of a new genus, Eodelphis, related to the opossums, redescription of *Thlæodon padanicus* Cope and critical estimate of the remaining Cretaceous mammals, with remarks upon the interpretation of the marsupial dentition.]
162. Methods of correlation by fossil vertebrates. Bulletin of the Geological Society of America, volume 27, pages 515-524. [Discussion of principles of correlation. The Equidæ are regarded as affording the best standard for Tertiary correlation.]

163. Kunz on ivory and the elephant. American Museum Journal, volume XVI, pages 485-495.

164. Record of progress in vertebrate palæontology (with C. R. Eastman and W. K. Gregory). Science, new series, volume XLIII, pages 103-110.

165. Supplementary note to T. Barbour's "Some remarks upon Matthew's 'Climate and evolution.'" Annals of the New York Academy of Sciences, volume XXVII, pages 11-15.

1917

166. News notes. A fossil tree trunk. (Unsigned.) American Museum Journal, volume XVII, number 1, page 78.

167. News notes. A Pliocene mastodon skeleton. (Unsigned.) Idem, volume XVII, number 2, page 148.

168. A fossil deer from Argentina. Idem, volume XVII, number 3, pages 207-211. [Notice of mounted skeleton of *Brachyceros pampæus*, with discussion of its affinities and the origin of the South American deer.]

169. A giant Eocene bird. Idem, volume XVII, number 6, pages 417-418.

170. News notes. Duck-billed dinosaurs—census of fossil skeletons. (Unsigned.) Idem, volume XVII, number 6, page 419.

171. Recent progress in paleontology (with C. R. Eastman and W. K. Gregory). Science, new series, volume XLV, pages 117-121.

172. Prehistoric animal life. The Mentor, Department of Natural History, volume V, number 13, August 15.

173. Gigantic Megatherium from Florida. (Abstract.) Bulletin of the Geological Society of America, volume 28, page 212.

174. The skeleton of Diatryma, a gigantic bird from the Lower Eocene of Wyoming (with Walter Granger). Bulletin of the American Museum of Natural History, volume XXXVII, pages 307-326, plates xx-xxxiii. [Description of a nearly complete skeleton of a gigantic flightless bird from the Wasatch formation of the Bighorn basin. It has a huge skull and enormous compressed beak like the extinct South American Phororhachos, but it is not related to that genus, nor nearly related to any other known type. Its affinities are difficult to estimate; although having some features in common with the ostriches and cassowaries it does not appear to be related to them, but to be a very ancient terrestrial adaptation derived from primitive neognathine ("carinate") stock. Suggestions as to its bearing upon the general problem of the evolutionary history of birds.]

175. A Paleocene bat. (*Zanycteris paleocenus.*) Bulletin of the American Museum of Natural History, volume XXXVII, article xx, pages 569-571.

176. Absence of the pollex in Perissodactyla. Bulletin of the American Museum of Natural History, volume XXXVII, article xxi, pages 573-577.

177. The Dentition of Nothodectes. Bulletin of the American Museum of Natural History, volume XXXVII, article xxxiii, pages 831-839. Nothodectes comes from a new fossil horizon at the top of the Paleocene, and is very closely allied to Plesiadapis of the Cernaysian of France. It is related both to Primates and Insectivora, especially to the Menotyphla.]

178. Man and the anthropoids. Science, new series, volume XLVI, number 1184, September 7, 1917, pages 239-240.

1918

179. The mounted skeleton of Moropus in the American Museum. American Museum Journal, volume XVIII, number 2, pages 121-123.
180. Skeletons of the Cuban ground sloths in the Havana and American Museums. Idem, volume XVIII, number 4, page 313.
181. A fortunate collector. Idem, volume XVIII, number 5, page 389.
182. A Tertiary alligator. Idem, volume XVIII, number 6, pages 505-506.
183. Fossils from Snake Creek beds. News notes. (Unsigned.) Idem, volume XVIII, number 8, page 731.
184. Vertebrate paleontology (with W. K. Gregory). American Year Book, pages 695-696.
185. Contributions to the Snake Creek fauna. With notes upon the Pleistocene of Western Nebraska—American Museum expedition of 1916. Bulletin of the American Museum of Natural History, volume XXXVIII, article vii, pages 183-229. [Fauna of the Snake Creek pockets recognized as including two distinct faunæ, Upper Miocene and Lower Pliocene, respectively. Various new types described. Revision of rhinoceros genera.]
186. A revision of the Lower Eocene Wasatch and Wind River faunas. By W. D. Matthew and Walter Granger. Part V—Insectivora (continued), Glires, Edentata. By W. D. Matthew. Idem, volume XXXVIII, article xvi, pages 565-657. [Revision of Insectivora and Glires, with description of various new or little known types. Description of a primitive genus of Metacheiromyidæ, with discussion of its affinities. Regarded as a very primitive edentate related to early Insectivora and collateral ancestor of armadillos and other Xenarthra on one side, of Pholidota on the other side. Tubulidentata not related to true edentates.]
187. Generic nomenclature of the Proboscidea. (Abstract.) Bulletin of the Geological Society of America, volume 29, page 141.
188. Affinities and phylogeny of the extinct Camelidæ. (Abstract.) Bulletin of the Geological Society of America, volume 29, page 144.
189. Notes on the American Pliocene rhinoceroses. (Abstract.) Bulletin of the Geological Society of America, volume 29, page 153.

1919.

190. Lawrence M. Lambe, obituary notice. Natural History (American Museum Journal), volume XIX, number 3, page 351.
191. Reply to a letter from John Burroughs. Idem, volume XIX, numbers 4-5, pages 491-493.
192. Affinities and origin of the Antillean mammals. Bulletin of the Geological Society of America, volume 29, pages 657-666.
193. Recent discoveries of fossil vertebrates in the West Indies and their bearing on the origin of the Antillean fauna. Proceedings of the American Philosophical Society, volume LVIII, pages 161-181.

1920

194. Honor to Adam Hermann. Natural History, volume XIX, number 6, pages 741-742. [Address on occasion of the retirement of Mr. Hermann, head preparator in the American Museum Department of Vertebrate Paleontology.]
195. The American Museum expedition to Jamaica. (Unsigned.) Idem, page 755. [Notice of the expedition of November, 1919, pointing out the evidence that the discovery of a fossil fauna will supply on paleogeography.]
196. Notice of expedition to the Agate Fossil Quarry. (Unsigned.) Idem, page 755.
197. Flying reptiles. Idem, volume XX, pages 73-81. [Notice of the Pteranodon skeleton placed on exhibition, with some general remarks on pterodactyls.]
198. John Campbell Merriam, new president of the Carnegie Institution. Idem, pages 253-254.
199. Abel's "Die Stämme der Wirbelthiere." Science, new series, volume 52, number 1322, July 9, 1920, pages 37-38.
200. A new genus of rodents from the Middle Eocene. Journal of Mammalogy, volume I, number 4, August, 1920.
201. Social evolution: A paleontologist's viewpoint. Natural History, volume XX, pages 374-378.
202. Three-toed horses. Idem, pages 473-478.

1921

203. Canadian dinosaurs. Natural History, volume XX, pages 536-544.
204. Proofs of the evolution of man. Idem, pages 574-575.
205. A note on the Cerhaysian mammal fauna. American Journal of Science, volume I, June, 1921, pages 509-511.
206. Notes on scientific museums of Europe. Natural History, volume XXI, pages 185-190, July, 1921.
207. The Cannonball Lance Formation. Science, volume LIV, July 8, 1921, pages 27-29.
208. New genera of Paleocene mammals (with Walter Granger). American Museum Novitates, number 13, September 6.
209. Stehlinius, a new Eocene Insectivore. Idem, number 14, September 7.
210. Life in other worlds. Science, volume LIV, September 16, pages 239-241.
211. Fossil vertebrates and the Cretaceous-Tertiary problem. American Journal of Science, volume II, October 1, pages 209-227.
212. [Dr. Mook's researches on Crocodilia.] Natural History, volume XXI, number 4 (notes), page 433.
213. Urus and bison. Natural History, volume XXI, number 6, November-December, 1921, pages 598-606.
214. Why paleontology. Natural History, volume XXI, number 6, November-December, 1921, pages 639-641.

1922

215. A superdreadnaught of the animal world. Natural History, volume XXII, number 4, July-August, 1922, pages 333-342.
216. The family Deinodontidæ, with notice of a new genus from the Cretaceous of Alberta (*Dromæosaurus albertensis*, new genus, new species) (with Barnum Brown). Bulletin of the American Museum of Natural History, volume XLVI, article vi, pages 367-385.

1923

217. Recent progress and trends in vertebrate paleontology. Smithsonian Report for 1923, September 30, pages 273-289.
218. Preliminary notices of skeletons and skulls of Deinodontidæ from the Cretaceous of Alberta (with Barnum Brown). American Museum Novitates, number 89, October 11.
219. New fossil mammals from the Pliocene of Sze-Chuan, China (with Walter Granger). Bulletin of the American Museum of Natural History, volume XLVIII, article xvii, pages 563-598, December 10. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 15.
220. The fauna of the Houldjin gravels (with Walter Granger). American Museum Novitates, number 97, December 18. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 16.
221. The fauna of the Ardyn Obo formation (with Walter Granger). American Museum Novitates, number 98, December 18. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 17.
222. New Bathyergidæ from the Oligocene of Mongolia (with Walter Granger). American Museum Novitates, number 101, December 28. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 19.
223. Nine new rodents from the Oligocene of Mongolia (with Walter Granger). American Museum Novitates, number 102, December 31. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 20.

1924

224. New insectivores and ruminants from the Tertiary of Mongolia, with remarks on the correlation (with Walter Granger). American Museum Novitates, number 105, January 18. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 22.
225. Third contribution to the Snake Creek fauna. Bulletin of the American Museum of Natural History, volume L, article ii, pages 59-210, issued July 3.
226. A new link in the ancestry of the horse. American Museum Novitates, number 131, September 23.

1925

227. Recent progress and trends in vertebrate paleontology. Reprinted from the Smithsonian Report for 1923, pages 273-289, in Bulletin of the Geological Society of America, volume 34.
228. Fauna and correlation of the Gashato formation of Mongolia (with Walter Granger). American Museum Novitates, number 189, October 7. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 56.
229. New creodonts and rodents from the Ardyn Obo formation of Mongolia (with Walter Granger). American Museum Novitates, number 193, October 27. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 57.
230. New ungulates from the Ardyn Obo formation of Mongolia, with faunal list and remarks on correlation (with Walter Granger). American Museum Novitates, number 195, November 19. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 58.
231. New mammals from the Shara Murun Eocene of Mongolia (with Walter Granger). American Museum Novitates, number 196, November 20. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 59.
232. New mammals from the Irdin Manha Eocene of Mongolia (with Walter Granger). American Museum Novitates, number 198, November 21. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 60.
233. The smaller perissodactyls of the Irdin Manha formation, Eocene of Mongolia (with Walter Granger). American Museum Novitates, number 199, November 23. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 61.

1926

234. Two new perissodactyls from the Arshanto Eocene of Mongolia (with Walter Granger). American Museum Novitates, number 208, February 16. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 64.
235. The evolution of the horse, a record and its interpretation. Quarterly Review of Biology, volume I, April, 1926, pages 139-185.
236. On a new primitive deer and two traguloid genera from the Lower Miocene of Nebraska. American Museum Novitates, number 215, May 10.
237. Early days of fossil hunting in the high plains. Natural History, volume XXVI, number 5, September-October, pages 449-454.

1928

238. A ballad of Pithecanthropus. Privately printed.
239. The evolution of the mammals in the Eocene. Proceedings of the Zoological Society of London, January 12, 1928, pages 947-985.
240. Xenotherium an edentate. Journal of Mammalogy, volume 9, February, pages 70-71.

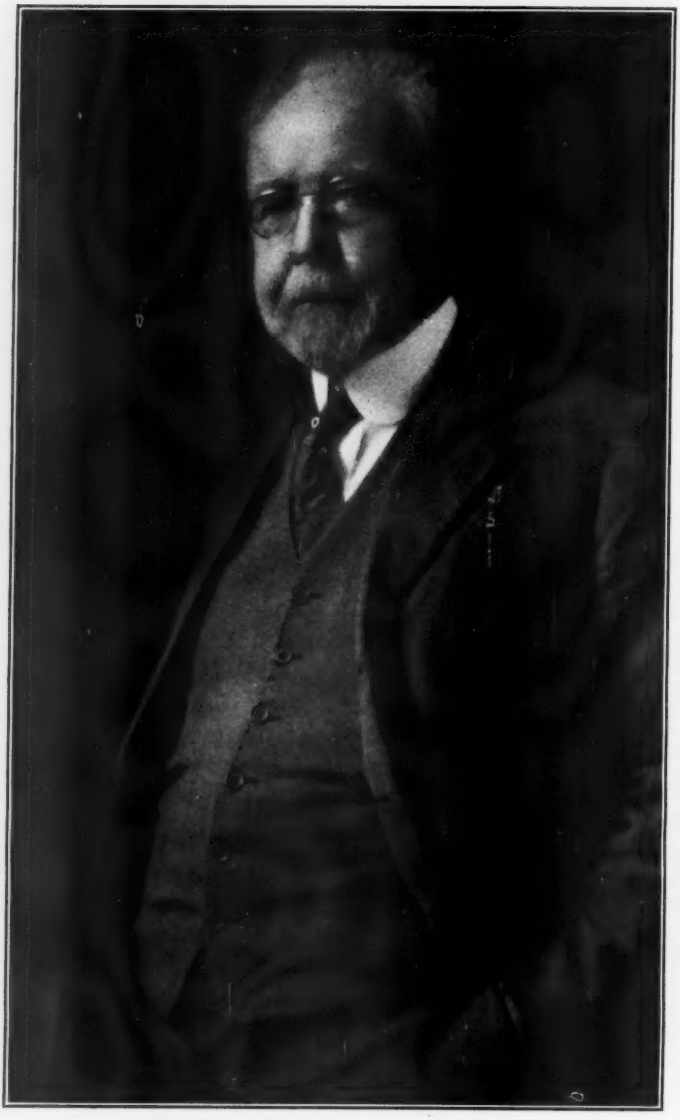
241. Outline and general principles of the history of life. Synopsis of lectures in paleontology I. University of California Syllabus Series, Syllabus number 213, August.
242. Paleocene multituberculates from Mongolia (with Walter Granger and G. G. Simpson). American Museum Novitates, number 331, October 30. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 86.
243. The ape-man of Java. Natural History, volume XXVIII, number 6, November-December, pages 577-588.

1929

244. A new and remarkable hedgehog from the later Tertiary of Nevada. University of California Publications, Bulletin of the Department of Geological Sciences, volume 18, number 4, January 29, pages 93-102, plates 7, 8.
245. Critical observations upon Siwalik mammals (exclusive of Proboscidea). Bulletin of the American Museum of Natural History, volume LVI, article vi, February 9, pages 437-560.
246. Preoccupied names. Stehlinella for Stehlinius; Prodiacidin for Palæolestes. Reprinted, Journal of Mammalogy, volume 10, page 171, May.
247. On the phylogeny of horses, dogs and cats. Science, May 10, 1929, volume LXIX, number 1793, pages 494-496.
248. Reclassification of the artiodactyl families. Bulletin of the Geological Society of America, volume 40, June 30, pages 403-408.
249. The phylum in zoology and paleontology. Science, August 9, 1929, volume LXX, number 1806, pages 142-143.
250. Additions to the fauna of the Gashato formation of Mongolia (with Walter Granger and G. G. Simpson). American Museum Novitates, number 376, October 7. Publications of the Asiatic expeditions of the American Museum of Natural History, contribution number 93.

1930

251. Osteology and affinities of Borophagus (with R. A. Stirton). University of California Publications, Bulletin of the Department of Geological Sciences, volume 19, number 7, May 9, pages 171-216, plates 21-34.
252. The phylogeny of dogs. Journal of Mammalogy, volume 11, May, 1930, pages 117-138.
253. Range and limitations of species as seen in fossil mammal faunas. Bulletin of the Geological Society of America, volume 41, June 30, 1930, pages 271-274.
254. The dispersal of land mammals. Scientia, volume 48, July, 1930, pages 33-42.
255. A Pliocene mastodon skull from California, *Pliomastodon vexillarius*, new species. University of California Publications, Bulletin of the Department of Geological Sciences, volume 19, November 26, 1930, pages 335-348, plates 41-44.



Geo. P. Merrill

256. Equidæ from the Pliocene of Texas (with R. A. Stirton). University of California Publications. Bulletin of the Department of Geological Sciences, volume 19, November 29, 1930, pages 349-396, plates 45-58.

1931

257. Critical observations on the phylogeny of the rhinoceroses. University of California Publications. Bulletin of the Department of Geological Sciences, volume 20, January 23, 1931, pages 1-9, 2 figures in text.

MEMORIAL OF GEORGE PERKINS MERRILL [1]

BY CHARLES SCHUCHERT

In the preparation of this memorial the writer has had the advantage of seeing, through the kindness of Mrs. Merrill, an autobiographical sketch prepared by her husband at the request of the National Academy of Sciences in April, 1924; and he is indebted for other information to Doctor Merrill's secretary, Miss Margaret W. Moodey. His personal acquaintance with Doctor Merrill began in 1893, covered ten years of work with him in the United States National Museum, and three years spent as a member of his family, and was kept alive after their paths diverged by correspondence and occasional contacts. Hence the following tribute is not only to a scientific colleague, but to a highly valued friend.

George Perkins Merrill was born May 31, 1854, at Auburn, Maine, and died there suddenly the morning of August 15, 1929. Each year he spent about a month at his summer home on the Isle of Springs at the seashore, and on the afternoon of the 14th he left the island to look up a reported find of large beryl crystals at Albany, Maine. That night he spent with his brother Horace at Auburn, and leaving early the next morning, he died suddenly of apoplexy in the railway station while waiting for the train. As Miss Moodey writes, "It seemed quite strange that he should have gone back to his birthplace and died there, and it is also there that he is buried. The funeral services were held on Sunday, the 18th, in a little church where his maternal grandfather preached."

Merrill's father, Lucius Merrill, a carpenter and cabinet maker, was a descendant of Nathaniel Merrill, who settled in old Newbury, Massachusetts, in 1633, and who is stated to have been one of the Huguenot de Merles who were driven out of France by the massacre of St. Bartholomew's Day, the name "Merrill" being a corruption. His mother, Anne, was the daughter of the Rev. Elijah Jones, of the First Congregational Church at Minot, Maine. There were seven children.

[1] Manuscript received by the Secretary of the Society January 21, 1931.

"The home being somewhat crowded," he says, "I lived for several summers with my grandfather in Minot, and after I had become of sufficient age to be of value, worked for three of them on the neighboring farm of my uncle. I was educated in the town schools of Auburn and the Lewiston Falls Academy, situated in Auburn, afterwards known as the Edward Little High School. I early became quite independent; at first doing small chores for the neighbors and then working with my father, and when at school acting as janitor of the building, and in later years, from 18 to 21, working in the shoe factories." During the winter of 1876 he taught school in Minot Center and during the vacations of the subsequent winters at East North Yarmouth. "My education up to the time I was 21 was necessarily scrappy, but in the winter of 1876 I entered the University of Maine, working my own way as in years previous and graduating in chemistry with the degree of B.S. in 1879. Later I received the honorary degrees of M.S. (1883) and Ph.D. (1889) from the same institution."

Immediately after graduating in 1879, Merrill became assistant to Professor W. O. Atwater in Wesleyan University at Middletown, Connecticut, working with him on the chemistry of foods. It was while here that he made the acquaintance of America's greatest pioneer in museum administration, Doctor G. Brown Goode, a graduate of that university and sometime curator of its museum collections, but at this time in charge of the United States National Museum. They liked each other at once, and it was this meeting, together with an earlier recommendation that will be referred to later, that had much to do with Merrill's subsequent appointment in the National Museum. In the winter of 1880-1881, Merrill was connected with the Fisheries Census at Washington, and in the following July transferred by Director Goode to the staff of the geological department of the National Museum as aid to Doctor George W. Hawes, who had in 1880 been appointed curator of geology. As we shall see, it was the latter who started Merrill on his geological career, and mainly along the line of petrology.

Merrill says in the sketch that he must have been born with a fondness for natural history, but adds:

> "If in my work there may have been any one controlling influence it must be attributed to the summers of my childhood which I spent with my grandfather. He was a man of far more scholarly standing than the majority of clergymen in like situations."

In the parlor of his house, he had a small collection of natural history objects and curios from "heathen lands," and—

"amongst the inorganic forms there was a curved piece of stone like the fragment of a saucer, or possibly the segment of a sphere. There was nothing remarkable about it had it not been that there rested in it a small spherical pebble, the two resembling an ironstone concretion familiar to geologists. I long afterwards learned that the two had had no connection whatever, someone having placed the pebble in the receptacle. It always excited my attention and I never failed to examine it when admitted to the room."

This curio found its later resting place over the fireplace of the living room in Merrill's home at Washington. Under the stimulus of this collection of his grandfather's, Merrill also became a collector, and he goes on to say:

"I soon had my room at home a far more diversified curiosity shop than anything displayed at my grandfather's. This indiscriminate collecting I carried through my school and college days, and so succeeded in impressing one of my influential friends, all unintentionally, that years afterwards he recommended me to the late G. Brown Goode of the Smithsonian Institution as a promising youth for appointment on his staff.

"I do not know that I had any very decided views on what profession I wished to take when I entered college. I had thought of civil engineering . . . but it was not long before I decided on chemistry and natural history as more to my taste and to these I gave most of my attention. Professor A. B. Aubert was then professor of chemistry and as it turned out I became his favorite pupil. . . . Our professor in natural history was C. H. Fernald. I became too one of his favorite students and acquired much information that helped me in my subsequent career. What I learned in geology was almost wholly my own; not a single field trip did we get, nor were we taught even the rudiments of field work. My first real geological trip was with Professor William North Rice, with whom I visited the contact between the trap and Triassic sandstone at Meriden, Connecticut, while assistant at Middletown."

Merrill was married in November, 1883, to Sarah, daughter of Joseph R. Farrington, of Portland, Maine. She fell seriously ill in 1892, and the family had to be divided between Maine and Washington. These were hard and trying days for the Merrill family. Mrs. Merrill died in 1894, leaving four children, Joseph Farrington, Anne Margaret, Mildred Hastings, and Ruth. In February, 1900, Merrill married Miss Katherine L. Yancy, of Virginia, by whom he had one daughter, Katherine Dorothy.

Physically, Merrill was about 5 feet 10 inches in height, of sturdy build, with sandy hair and keen blue eyes. Alert and active, he was always occupied, spending most of his evenings reading, not only the scientific

publications of the day, but the best literature as well; on his table invariably lay copies of the poems of Robert Burns and the "Rubaiyat" of Omar Khayyam—in fact, he was ever a lover of poetry and of music. A typical "down East Yankee," he appeared on first acquaintance to be austere, reserved, and pessimistic, but to his many friends, though always critical, he showed a loyal and generous heart. Those who met him as host or at any social function found him unsurpassed in humor and in apt quotation.

Doctor Merrill's thought was rarely, if ever, speculative. As Farrington (1930) says, "He preferred to keep close to facts and allow time and accumulation of further data to furnish their interpretation," a tendency to which he himself bears witness when he states that he prefers in his daily work "to be always afloat in regard to opinions in geology" (1913*a*, page 67). His ideals of what qualities a geologist should possess may be read in his statement at the centenary of the birth of James D. Dana, whom he greatly admired. A geologist, he says, first—

> "must be a good observer. Second. He must be sufficiently grounded in certain basal sciences to enable him to draw legitimate conclusions from what he observes. Third. He must know what other workers have done, and be able to utilize to advantage their work and conclusions. Fourth. He must have staying power. Fifth. If he is a *great* geologist he must possess a creative imagination and be master of both inductive and deductive methods of reasoning" (1913*a*, pages 64-65).

Merrill was a Government officer in the United States National Museum for nearly a half century (1881-1929). His official and scientific career there will be presented under four headings as follows:

I. As organizer of the Department of Geology in the National Museum.

II. As pioneer in the study of building stones and the processes of rock-weathering.

III. As pioneer in the application of petrology to the study of meteorites.

IV. As pioneer historian of North American physical geology.

MERRILL AS ORGANIZER OF THE DEPARTMENT OF GEOLOGY IN THE UNITED STATES NATIONAL MUSEUM

As previously stated, Merrill began his long and fruitful Washington career in the winter of 1880-1881 as aid in the United States Fisheries Census. The following July he was transferred to the Division of Geology in the National Museum, which had been started in 1880 in charge of Doctor George W. Hawes. Hawes died in 1882 and the Division of

Geology was rearranged, Merrill being placed in charge of petrology or lithology and physical geology. "The years immediately following the death of Hawes were full of hard work and much trial." In 1887 he was appointed curator of the division. Two years later he was promoted to full curatorship, and in 1897 to head curatorship, of the newly organized Department of Geology, embracing the divisions: (1) Physical and Chemical Geology, with Merrill as curator; (2) Mineralogy; and (3) Stratigraphic Paleontology.

As is well known, Merrill proved himself one of the most effective of museum exhibitors and husbanders of geologic materials. Under his care the Department of Geology in the National Museum grew from a small and insignificant beginning to one of the great collections of the world, and one which possibly is not excelled by any.

Anyone who has held a curatorship in a large museum knows that most of his time goes into the husbanding of the collections in his charge, and into taking care of the daily routine. Research is secondary and must be carried on in time remaining after the performance of these official duties. It is therefore only by the most careful planning that any research can be accomplished at all. How well Merrill made use of his time and facilities is attested by his bibliography of nearly 200 titles, many of which are long papers and books. In addition he wrote 47 annual reports of his department, and was a contributor of articles to at least six dictionaries and cyclopedias. Furthermore, in the years 1893 to 1916 he held the chair of geology and mineralogy and lectured after official hours several times each week during the college year to undergraduates in the Columbian (now George Washington) University, finally retiring on account of ill health. He also was lecturer in the Maryland Agricultural College in 1890-1891.

In 1883 appeared Merrill's first report as curator, in the course of which he says that he has in his keeping about 12,500 specimens. Six years later (1889) he feels that his department is in good condition, "having become fairly established." In 1891 the department has "at last emerged into a systematic series of collections, designed to show something regarding the earth's structure and history and the extent to which its resources are utilized by man." His section now had about 35,000 specimens, and that of mineralogy about 25,000 more.

The Department of Geology, starting thus in 1880 singlehanded, had in 1929 grown to a staff of 19 paid or honorary curators and associates. In the way of material wealth the various sections then had in their reserve and exhibition collections the following number of specimens:

Section of Geology	93,044	
Section of Mineralogy and Petrology	132,279	
		225,323
Section of Stratigraphy or Invertebrate Paleontology		1,765,600
Section of Vertebrate Paleontology		24,497
Total		2,015,420

Truly a remarkable growth!

MERRILL AS PIONEER IN THE STUDY OF BUILDING STONES AND THE PROCESSES OF ROCK-WEATHERING

Merrill appears to have been the first to make a systematic study of stone for building purposes, and in America the first also to study in detail the processes involved in rock-weathering. "No material," in his belief, "has yet been found so well adapted to the nobler forms of architecture as stone." At the basis of this work lies the science of petrology, which deals with the microstructure and chemical nature of rocks. It was along these lines that Merrill's greatest activity lay between 1881 and 1905 and during these years he published upward of 80 papers and books, a total of 40 per cent of his entire bibliography.

The history of the upwelling of any science is interesting. Regarding that of petrology, Merrill wrote as follows (1924*a*): Prior to 1870 the microscope was used hardly at all in determining the structure and mineral composition of rocks. The seed of the new science of petrology, planted by Clifton Sorby of England in 1850, was developed first by Zirkel and then by Vogelsang. By 1873 microscopical petrology had become established as a recognized department of geological research. Then came the great book of Rosenbusch in 1877, and in 1879 that of Fouqué and Michel-Levy. The new science took root in America first in Michigan in 1873, but the first public announcement of its introduction in this country was made by Edward S. Dana at the Hartford meeting of the American Association for the Advancement of Science in 1874, when he summarized a microscopic study made by Hawes and himself of the trap of the Connecticut Valley.

Merrill's reasons for going into petrology he gives as follows:

"My abrupt shift from chemistry to geology was due purely to a newly made friendship with Doctor Hawes who was at that time one of the leading authorities on microscopic petrology, a branch of study then just coming into vogue. It was understood at the time of my accepting this position [in the National Museum], that there being no university in America where this branch of

geology could be studied, I should be assisted in taking it up by Dr. Hawes, but unfortunately owing to his failing health this part of the agreement was never carried out."

Merrill's first duty in the Museum was the cutting of thin sections of the entire collection of some 4,000 samples of building stones that had been brought together from upward of 1,500 quarries in the United States, together with many from foreign countries—"the most systematic and complete collection of its kind in any museum in the world." Each specimen was examined under the microscope "in order not only to determine what the rock was, but also to ascertain if it contained any mineral constituents liable to unfavorable change on exposure to the weather" (1885*a*, page 521).

This work on building stones naturally led to his first book, "The Collection of Building and Ornamental Stones in the United States National Museum" (1889*c*). Merrill continued this work along the same lines on his own initiative, traveling and visiting quarries, examining old stone buildings whenever opportunity offered, and collecting data on weathering properties. Then he rewrote the book and published it as "Stones for Building and Decoration" (1891*b*). Of all his writings, none had a wider circulation. It treats of the geographic distribution of building stones in the United States, their minerals, their physical and chemical properties and weathering qualities, and gives suggestions on their selection and testing. The book passed through three editions (1891, 1897, 1903), and was, as he says, "the first systematic work of its kind to appear in America, and I believe I may say was the chief instigator of the numerous investigations by state surveys along the same lines which were undertaken later." It established his reputation as authority on the subject, and until the Bureau of Standards was established, the Government repeatedly called for Merrill's opinion on the stones to be used in its various buildings.

With regard to his work on rock-weathering, Merrill says:

"It is perhaps but natural that my attention having been called to the weathering of rocks when used for building purposes I should have turned my thoughts next to this particular phase of geology. The field was an inviting one and indeed the amount of superficial decomposed material overlying the rocks in the District of Columbia had early attracted my attention, since I had come from a glaciated region where like phenomena were almost wholly unknown. The results of my studies in this line were very favorably received. The main results were brought together in my treatise, 'Rocks, Rock-weathering and Soils' [1897]. In the preparation of this volume, I had not only collected my own materials, made my own sections, but also many of the

separations and chemical analyses, a detail which in the present condition of chemical science I should scarcely dare to attempt."

This book of Merrill's was a unique one, there being nothing quite comparable; it has been a source from which compilers of textbooks on agriculture have drawn their materials for many years. As Dr. Harvey W. Wiley has said, "Dr. Merrill is the most complete authority on soils. . . . He has given much to geology but has given much more to agriculture—how much the public will never know." In Europe, according to Farrington, it is for this work on rocks and rock-weathering that Merrill is best known.

Rocks disintegrate, alter, decompose, and dissolve under all climates, but the decomposition is most apparent, Merrill states, under moist and warm conditions. In rock-weathering,—

"hydration is an important factor, the amount of water increasing rapidly as decomposition advances. In the earlier stages of degeneration it is doubtless *the most* important factor. There is, moreover, among the siliceous crystalline rocks, in every case a loss in silica, a greater proportional loss in lime, magnesia, and the alkalies, and a proportional increase in the amounts of alumina and sometimes of iron oxides, though the apparent gain may in some cases be due to the change in condition from ferrous to ferric oxide. As a whole, however, there is a very decided loss of materials. Among siliceous crystalline rocks, this loss, so far as shown by available analyses and calculations, rarely amounts to more than 60 per cent of the entire rock mass. Among calcareous rocks, on the other hand, it may, in extreme cases, amount to even 99 per cent" (1906*a*, page 220).

As sedimentary rocks are composed of disintegrated and decomposed materials, it follows that such, with the exception of the purely calcareous varieties, will undergo less chemical change than the crystalline ones.

"The processes involved in the disintegration of the sandstones, shales and argillites are mainly mechanical, with the exception of those which carry a feldspathic or calcareous cement." In the calcareous members, "the process is almost wholly chemical, and notable for its simplicity. . . . The process is one of superficial solution. . . . So it happens that hundreds or even thousands of feet of strata may be removed without leaving more than a very thin coating of soil in its place" (1896*c*, page 871).

About Washington, Merrill had observed granitic rock "so disintegrated at a depth of 80 feet from the present surface as to be readily removed by pick and shovel." About Atlanta, Georgia, "the rocks are 'completely rotted' to a depth of 95 feet, while 'incipient decay' may reach to a depth of 300 feet" (1906*a*, page 271).

The unconsolidated rock material over the earth's surface Merrill called the regolith, from Greek words meaning a blanket of stone (Ibid., page 287).

In regard to soils, Merrill says that their prevailing mineral constituents are—

"nearly always silica, with varying amounts of alumina, oxides of iron, lime, magnesia, and the alkalies. A small amount of organic matter, from extraneous source, is usually present. This prevalence of silica and alumina, as may be readily understood, is an essential consequence of soil formation through the breaking down of rocks by the processes of weathering, whereby all but the most indestructible portions are lost" (Ibid., pages 345-346).

The task of overhauling and installing the nonmetallic economic collections in the National Museum was taken up by Merrill in 1889, resulting not only in a greatly improved exhibition collection but as well in a book, "Guide to the Study of the Collections in the Section of Applied Geology; the Nonmetallic Minerals" (1901*c*). The popular demand for this shortly exceeded the supply, and it was republished in modified form by John Wiley and Sons as "The Nonmetallic Minerals" (1910*b*).

MERRILL AS PIONEER IN THE APPLICATION OF PETROLOGY TO THE STUDY OF METEORITES

General statement.—No geological problem interested Merrill more than that of meteorites, and of his entire bibliography of about 200 titles no fewer than 80 have to do with these most interesting celestial bodies. The first three papers appeared in 1888 and the last one after his death, while the twenty years of greatest activity began with 1907.

In 1880 the National Museum had about ten falls and finds, among which were the large irons of Tucson and Casas Grandes. In 1888 the the number had increased to 128 specimens, with 156 additional ones in the Shepard Collection, which was placed on deposit in 1887 and became the property of the Museum in 1917. Most of the specimens in both collections were small. By 1902 there were all told 348 different meteorites, of which 143 were irons; and, in 1916, 412 distinct falls and finds were represented. Merrill alone described 40 new falls. Of the Cañon Diablo find, the collection has 400 specimens weighing 2,200 pounds; and of the Holbrook one over 600 complete individuals. As Farrington has well said (1930), "In this as in all of his undertakings Merrill achieved remarkable success," building for the National Museum one of the great meteorite collections of the world, probably the sixth one in numbers of falls and finds.

A meteorite, according to Merrill, "furnishes tangible testimony of the nature of materials existing outside of our solar system, and affords, aside from the spectroscope, the only clue to the matter of which celestial bodies are composed." Truly, meteorites are chips of other worlds (Weltspäne), as the German Chladni said in 1794—"the remains of worlds gone to pieces" (1916*a*, page 13). Not over three or four are found each year, and the number of all the iron and stony meteorites in the museums of the world is fewer than 1,000 and their total weight not over 200 tons (1925). Moreover, of all the known meteorites only about one-half have been seen to fall and have then been found; these are called falls, those discovered without having been seen to fall being labeled finds. Of the falls, only ten are irons, and accordingly most of the known metallic ones are finds. Usually a fall consists of a single specimen, but among the stones the individuals of a single fall number at times thousands and in two cases each fall yielded as many as 100,000 stones.

Constitution of meteorites.—The meteorites of celestial space show "so great a uniformity of material yet so individualized that one conversant therewith can tell almost at a glance whether celestial or terrestrial in origin" (1930, page 47). Even though the elemental matter of meteorites "may be the same as in terrestrial rocks, the form of combination is at times radically different and of a nature to indicate that they formed under conditions quite unlike those existing on the earth today, and particularly so with reference to the presence of free oxygen and moisture" (1916*a*, pages 1, 5).

In all known meteorites, there is nothing present of the nature of a true vein-rock, a terrestrial sedimentary or a metamorphic or pumiceous one, "and nothing in content of silica, alumina, lime, or alkalies corresponding to the granites." Many meteorites have undergone metamorphism, and all known ones "are composed of volcanic materials . . . comparable with more or less compacted and altered masses of volcanic ash or tuff." All meteorites "are of a basic nature, related closely to the basalts, pyroxenites, and peridotites among terrestrial forms" (1919*a*, page 184; 1930, pages 39, 45).

In another paper, Merrill holds that meteorites are the result of explosive activity in a dry and oxygen-free atmosphere. Stony meteorites are therefore not of earthly origin. Their iron—

> **"is secondary and probably owes its reduction to metallic form to the influence of hydrogen. . . . The fact that the stones show the effect of heat and rapid cooling may, perhaps, be accounted for on the cometary hypothesis—that their brief stay in the proximity of the sun was followed by so rapid a retreat as to prevent a complete recrystallization of the fused material" (1921*b*, page 414).**

For what they teach, the most interesting meteorites are the stony ones, the aerolites. These so-called chondritic meteorites have small spherical and oval grains known as chondrules (from the Greek word for grain) and composed of silicate constituents, "the formation of which affords one of the most interesting puzzles in connection with the origin of meteorites."

Mineralogically, the chondrules are composed chiefly of olivine or pyroxene.

"Some are largely of an undifferentiated glass. Feldspars occur but rarely except in the form known as maskelynite. In addition are occasional enclosures of metal or metallic sulphides, chromite or other minor constituents" (1920*d*, page 450).

Merrill in 1916 thought that the chondrules might be looked on as the solidified molten drops of a "fiery rain" or world-making mist. Later, however, after a study of all the thin sections of stony meteorites in the National Museum, he changed this view, saying:

"In none of them do I find chondrules developed in the variety and perfection of forms existing in those meteorites which are plainly tuffaceous. This fact and others . . . have led me to regard the larger part if not all chondritic stones as originally tuffaceous and owing their more or less crystalline condition, where such exists, to heat and pressure in a nonoxidizing or even reducing atmosphere" (1920*d*, pages 462-463).

Merrill concludes with Suess that—

"the earth today, in its course, is but passing through and receiving from space a deposit of materials representing one and the same original body, and that body one of an exceeding basic nature, not necessarily resembling, in percentage composition, the materials which may have reached us during past and earlier stages of earth history" (1909*c*, pages 473-474).

From the standpoint of either the meteoritic or planetesimal theory of world origin, Merrill says:

"we are bound, as it seems to me, to regard the meteorites as world matter. If so regarded, we are confronted at once with the general basic nature of the original magma from which they were derived."

Having regard only for the stony meteorites,—

"it appears that in but a few instances does the silica rise above 50 per cent. Alumina is likewise low, only in the basaltic forms rising even as high as 14 per cent. The percentage of lime is also low, while the alkalies are rarely present in amounts up to even 1 per cent. Magnesia, on the other hand, is

almost invariably abundant, the amount at times rising as high as 40 per cent.

"Now with our present knowledge regarding the composition of the earth's crust, of the relative proportional abundance of the basic and acidic rocks, I feel that it is self-evident that no amount of chemical differentiation of such a magma as that presented by the meteorites could bring into existence such a body as that of our earth *so far as its composition is yet revealed.* It is to be noted, however, that we have no direct evidence as to the chemical nature of meteoritic matter that may have come to the earth in past ages" (1919*a*, pages 187-188).

Meteor crater.—Probably the most remarkable phenomenon thought to be connected with the falling of meteorites is a craterlike circular hole about 4,000 feet in diameter and 600 feet deep, known as Meteor Crater, situated 12 miles southeast of Cañon Diablo, Coconino County, Arizona. In the summer of 1906 Merrill was detailed by Secretary Walcott of the Smithsonian Institution to make a study of this so-called Coon Butte or Meteor Crater. During his examination he had the guidance of Mr. D. M. Barringer, a mining engineer who had been unsuccessfully exploiting the place in the hope of recovering the main mass of the meteorite.

Meteor Crater has a raised rim, which stands from 120 to 160 feet above a plain made of horizontal strata of Permian age. At the surface is the buff arenaceous Kaibab limestone and beneath it the very porous, gray, highly siliceous Coconino sandstone, with a thickness greater than 400 feet. Ever since this great hole was found, geologists have been asking, Was it made by a blow-out from within or is it due to the external impact of a meteorite?

The rim of the crater, according to Merrill (1908*a*), is composed of loose unconsolidated rock fragments of all sizes, from microscopic dust to blocks weighing thousands of tons. The crater walls—

"are composed of the crushed, broken, and bent strata of the limestone and sandstone forming the floor of the surrounding plain, and which dip away from it in all directions [the dips vary between 10 and 80 degrees]. Perhaps the most significant feature of the ejectamenta is the occurrence of enormous masses of the sandstone which have undergone a partial metamorphism through crushing and heat. . . . This material must have come from a depth of at least 300 feet below the original surface." There is also a vast amount of a chalky white siliceous rock-flour, the shattered grains of the gray sandstone. Outside of the rim "are many low, rounded, moraine-like deposits composed of the same material as the rim, but for the most part in a comparatively fine state of disaggregation." All of the material "was in the air at the same moment of time and was deposited 'pell-mell,' wholly without order or reference to gravity, as it fell to the ground."

The Cañon Diablo iron meteorites found on the rim and the adjacent plains are "the most interesting and instructive of known meteorites," and they contain small black and white diamonds. At least 20 tons of these irons are known to have been gathered over several square miles of the ground about the crater; in number they run into the thousands and in weight from one gram up to 1,013 pounds.

Merrill concludes from the shape, size, and ejected material of Meteor Crater that the evidence points strongly—

> "to an origin by impact. It is difficult, if not impossible, to conceive of the smashing and metamorphism of the sandstone on any other ground. The sand grains are crushed in a manner that could be brought about only by some sudden shock. . . . The fused quartz indicates great heat. . . . The slightly disturbed and unchanged condition of the deeper-lying sandstone seems to prove the superficial character of the phenomena." The infall of meteoritic material "seems worthy of serious consideration" (1908*a*, pages 489-490).

Twelve years later Merrill wrote a second paper on Meteor Crater for the benefit of astronomers, reaffirming his original view.

The place of meteorites in the solar system.—Students of meteorites are now all agreed that they are celestial bodies fallen on our earth. Farrington regards them as "portions of extra-terrestrial bodies," in other words, as "fragments of some pre-existing body rather than independent celestial bodies" (Meteorites, 1915, page 211). According to Chamberlin, however, the meteorites are independent members of the solar family, originating out of the sun when it was interfered with by a far larger intruding body. This approach caused mother sun to give birth to her very numerous family of planets and their satellites, to the erratic comets, to the meteorites, and to the chondrules. The careful student must keep clearly in mind the fact that Chamberlin [2] regards planetesimals and chondrules as the world-making stuff born of the sun. The planetesimals "revolve concurrently in a narrow disk and are thereby fitted to collect into planets"; the wide-sweeping chondrules are not so restricted, but gathering into swarms remain discrete and compose the heads of the very erratic comets; still other chondrules, revolving close about the sun, gather into the meteorites and are from time to time more or less completely fused or metamorphosed.

MERRILL AS PIONEER HISTORIAN OF NORTH AMERICAN PHYSICAL GEOLOGY

It was but natural, in his position as head curator, that Merrill should have to know something of the connections, education, and career of his

[2] The two solar families, Chicago, 1928.

colleagues and his predecessors, and in his administrative work it was often necessary for him to look up the records of the early Government surveys with a view of ascertaining the final disposition of their collections. Having this information, he began to lecture to his students at the university about these surveys and the older generation of geologists. This led him to devote "odd moments" in his official life to the study of the rise and progress of American geology, with the result that he became the historian of our science previous to the present century. He wrote memorials of James D. Dana, John W. Powell, Joseph P. Iddings, George F. Becker, George W. Hawes, Carl L. Rominger, Edward T. Cox, and W. S. Yeates; and brief sketches of nearly 200 American geologists were combined in 1906 to form his "Contributions to the History of American Geology," which was the first book of its kind. In addition, he prepared many shorter sketches for the "Dictionary of American Biography," now being published.

The purpose of the "Contributions" appears in the following statement in regard to the pioneers in American geology:

"They had received little or no preliminary training along these special lines, and had access to but few books. The information with which the geologist of to-day begins his career did not then exist, and an effort has here been made to show by what years of toil each new fact has been unearthed, cleansed of the debris which obscured its outlines, and treasured up in such form that it is now possible for the student, in a few short years, to encompass the garnerings of a century" (page 191).

In 1924 the Yale University Press brought out this book, very largely rewritten, under the title, "The First One Hundred Years of American Geology." Schuchert in reviewing it said:

"It is a history of the growth of geology in America in all of its physical aspects. Beginning with 1785, it goes on to the closing years of the past century—a review of the gradual development of the science in this country through one hundred years. . . . It is an impressive volume."

Early American geology, according to Merrill,—

"was preeminently a science of observation and deduction. Information on which to base theory and hypothesis was not available—indeed, did not exist. With the accumulation of recorded observations it became possible to carry conclusions beyond the point of mere observation, and the inductive method was evolved. Well toward the close of the period . . . synthetic methods of research were introduced by which the attempt is being made to discover by actual experiment in the laboratory the correctness or falsity of deduction or of inductive reasoning" (1924, preface).

Merrill also wrote "Contributions to a History of American State Geological and Natural History Surveys" (1920*a*). This history is arranged by states alphabetically.

In the course of his historical research Merrill accumulated portraits and autograph letters not only of most of the American pioneers but of a great many other American geologists as well, and this very valuable collection has now been given to the Museum in which he labored so long.

MERRILL'S HONORS

Merrill was elected to membership in the National Academy of Sciences in 1922, thus receiving the greatest honor that can come to a man of science in America; and in that same year he was awarded the J. Lawrence Smith gold medal of the Academy. He was a member of the American Philosophical Society, the Academy of Natural Sciences of Philadelphia, the Washington Academy of Sciences, the Geological Society of America (vice-president, 1920), the Geological Society of Washington (president, 1906-1907), and the Maryland Academy of Sciences, and was a corresponding member of the American Institute of Architects and several other organizations. He was a member of Phi Beta Kappa, of Phi Gamma Delta, and of Phi Kappa Phi.

Of honorary degrees, Merrill held the M.S. and Ph.D. from the University of Maine, and the Sc.D. from George Washington University.

A very great honor, and certainly a most enjoyable one, came to Doctor Merrill on the evening of his 75th birthday, May 31, 1929, when he was given a testimonial dinner by his many friends and his colleagues from scientific circles. At the dinner there was presented to Merrill a bound volume of more than 200 letters of congratulation and esteem. Concluding his thanks with lines expressive of a hope based on T. B. Brown's well-known poem, Merrill said:

> "'I stand upon the summit of my years.'
> So may it ever be,
> Not bowed beneath their weight
> With feet firm planted
> And soul undaunted
> I'll stand and contemplate
> What time has wrought
> And tremble not
> For what was, is,
> Or is to be,
> I'll stand upon the summit of my years."

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MEMORIAL OF HORACE BUSHNELL PATTON [1]

BY G. M. BUTLER

The death of H. B. Patton, Ph.D., Sc.D., at Atascadero, California, on July 15, 1929, brought to a close a long life of usefulness and devotion to a very high conception of duty. Born in Chicago on September 18, 1858, he graduated from a local high school and then went to Amherst, which conferred its A.B. degree upon him in 1881. After spending two years at Howard University, where his father, Reverend W. W. Patton, was for many years President, he went abroad to study under Zirkel at Leipzic and Rosenbusch at Heidelberg. The degree of Doctor of Philosophy *summa cum laude* was conferred upon him by the latter institution in 1887, and he remained there as an assistant for a short time. He returned to the United States in 1888, taught for brief periods at Howard and Rutgers, and in 1891 became a member of the faculty of the Michigan College of Mines and assistant geologist with the Michigan Geological Survey. In 1893 he was called to the Colorado School of Mines as professor of geology and mineralogy, which position he filled most honorably until 1917—almost a quarter of a century. While there he served for several years as geologist with the Colorado Geological Survey. Some time after he retired from teaching, the trustees of the Colorado School of Mines appointed him emeritus professor of geology and mineralogy in recognition of his long and highly satisfactory service, and, at the semicentennial exercises of the University of Colorado in 1927, he received the honorary degree of

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Henry B Patton.

Doctor of Science. He served as vice-president of the Geological Society of America and was an active member of several other organizations, including the Colorado Scientific Society, Tau Beta Pi, and Chi Phi. After he left the Colorado School of Mines, he engaged in the practice of his profession, at first for the Union Pacific railroad and later as a consultant for many companies. On June 10, 1904, he married Louise Alice Torry and is survived by her and by an adopted daughter, Dorothy.

The writer first met Dr. Patton in 1898 when he entered the Colorado School of Mines as a student, and for fifteen years thereafter his association with him was close and continuous. As a companion and assistant on long summer mineral collecting trips, as an undergraduate and graduate student under him, as a member of his faculty, and as an active fellow worker in his church, he probably knew Dr. Patton more intimately than anyone else during the most active and productive period of his life, and grew to feel respect and affection for "Bunson," as he was called by all his students, such as one man rarely engenders in the heart of another.

For a number of years after Dr. Patton joined the faculty of the Colorado School of Mines, he taught all the geological and mineralogical subjects offered by that institution. Although the burden of his duties was naturally very heavy, he bore it with an enthusiasm and devotion that was an inspiration to his students. He demanded a high quality of work from the young men who studied under him, but he was very patient and absolutely fair in his dealings with them. These qualities, together with his really brilliant work in the field and laboratory, so impressed his students that it is certain that no other member of the faculty was as respected or so endeared himself to the young men who came under his influence. His former students will never forget the field trips in which he would regularly out-walk and out-climb the younger and supposedly more vigorous members of his class. Nor will stories of his absentmindedness, so typically "professorial," soon be forgotten. When a student questioned him on any subject, he would almost invariably reply with one or more questions which forced the inquirer to solve the problem for himself. When one of the boys expressed an opinion, Dr. Patton would compel him to defend his thesis by expressing doubt of the correctness of his conclusions and proposing an alternative theory. His students were forced to think and not merely memorize facts.

Of an intensively religious nature, Dr. Patton's activity in church work was hardly less than in teaching and research. A considerable

proportion of his income was devoted to the support of the Presbyterian Church in Golden, and he held all the offices in the gift of that congregation. Possessed of a fine bass voice, he directed the choir, and for some time served as a lay preacher in several chapels established in mountain communities west of town. Although very tolerant of the frailties of others, his every act exemplified his conception of what the Christian life should be, and he was completely free from habits that are commonly considered vices. His life was a splendid refutation of the frequently expressed claim that science and religion are antagonistic.

During most of his career, Dr. Patton was unable to devote much time to research, but his accomplishments along that line are not inconsiderable, as is indicated by the appended incomplete bibliography, and proved his ability. He is probably best known for his work with Dutton on Crater Lake and his paper on "Rock Streams," read before the Geological Society of America, in which he proved that streamlike accumulations of angular rock fragments found on Vita Peak, in Southern Colorado, were the result of slow creep and were not glacial. His work on the geology and ore deposits of the Montezuma, Gray Back, Alma, and Platoro-Summitville mining districts, which was done in collaboration with the Colorado Geological Survey, is also considered very meritorious, but he was most interested in rocks and minerals, and the majority of his publications are on these subjects. He was instrumental in accumulating splendid collections at Golden, and developed strong courses in crystallography, determinative mineralogy, and petrology in which the emphasis was strongly placed on "sight determination."

A gentleman in the best sense of that much abused work, kindly, sympathetic, and benevolent, a scholar who inspired all who worked with him, a man of fine physique and appearance and splendid character who consistently exemplified the highest ideals, Dr. Patton made a host of friends who will greatly miss his cheery smile and helpful advice. His work is finished, but for many years he will live in the memories and lives of hundreds of young men who will long think of him with affection and reverence.

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MEMORIAL OF ROLLIN D. SALISBURY [1]

BY ROLLIN T. CHAMBERLIN

Many students who have attended the University of Chicago, and probably others from Wisconsin and Beloit College in earlier years, when asked who was their greatest teacher, have replied without hesitation, "Professor Salisbury." To many of them he was the ideal teacher. His flashing personality fascinated the students; frequently outcropping bits of brilliancy kept them continually on the *qui vive* for thrills; and a never-lapsing autocracy maintained the strictest order. His classroom was no place for the dull or the slow, but the better students profited enormously. So strongly did he influence their thoughts and behavior that in after years when they in turn were teaching, one after another has been criticized for "trying to ape Saul." The manner and methods did not seem right without the master.

Daniel Salisbury, father of the subject of this sketch, left his boyhood home in Cortland, New York, and came west in 1836. He made much of the journey on foot and finally located between Elkhorn and Burlington in southeastern Wisconsin, being the second settler in Walworth County. After the death of his first wife, Daniel Salisbury married Lucinda Bryant, who was distantly related to William Cullen Bryant. Rollin, next to youngest of the six children, was born August 17, 1858.

Their farm was a small one of eighty acres but well tilled and looked after with much care. Daniel Salisbury was a very particular man. Neighborhood gossip had it that he would plane the ends of the sticks of wood in the woodpile before he set up another tier. All the children were taught at an early age to have a share in the duties of the farm and household, and the training appears to have been strict. The habit of careful attention to details, acquired early, was ever after to loom large in the life of Rollin Salisbury.

Rollin attended the small country school a mile and a half away until just after his sixteenth birthday, when he went to the State Normal School at Whitewater. Completing the four-year course in three years, he taught school a year and entered Beloit College in 1878. Here he attracted the attention of Professor T. C. Chamberlin and thus began the lifelong association which was to mean so much to both men. To Rollin, inclined to pessimistic moods at times, the friendly, optimistic counsel of his more experienced teacher was just what was needed to instill in him the necessary confidence in himself to enable him to make

[1] Manuscript received by the Secretary of the Society February 2, 1931.

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the most of his latent talents. He was a painstaking student, motivated by high ideals, but he had as yet not really found himself.

He graduated in 1881 just as Chamberlin was giving up his professorship to take charge of the new glacial division of the United States Geological Survey. Two years later Salisbury became assistant professor of geology, zoology and botany in Beloit College and professor the following year. The timidity expressed in his letters to intimate friends at that time contrasts strangely with the domination and commanding tone of later years. Yet both of these seemingly contradictory traits were fundamental elements in his nature. He was struggling steadily ahead.

An interruption in Salisbury's teaching occurred in 1887 when he went to Germany for a year of further study. During the first summer he found and traced a great moraine belt from Denmark to Russia which had not been adequately recognized. The school year was passed at Heidelberg, devoted principally to work under Rosenbusch in mineralogy and petrography and to gathering experience in the German methods of education.

Broadened by the foreign experience, his teaching at Beloit became extraordinarily successful, and when in 1890 the rumor spread that he had received a call to the University of Wisconsin, a petition urging him to stay was promptly circulated and signed by practically every student in the college. So affected was he by this spontaneous expression of regard by the student body that he declined the offer. But the offer was renewed the next year and he went to the larger institution.

Glacial geology was the field of Salisbury's greatest interest. In the Sixth Annual Report of the United States Geological Survey, 1885, appeared the joint contribution with T. C. Chamberlin "On the driftless area of the upper Mississippi Valley." Though the field work must have been done at a rapid rate, judging from the scope and extent of the investigation, the results reflect meticulous care in observation guided by exceptional insight into the problems involved. This was Salisbury's first paper of general importance. The result was to make the driftless area famous in Pleistocene geology.

Later he worked southward. The "Orange sands" of the Mississippi Valley beyond the recognized limit of glaciation were found to comprise little or nothing capable of further oxidation. Prolonged subaerial exposure was inferred, and the complete absence of northern material such as would be brought by drainage after the appearance of the first ice-sheet forced the conclusion that the Orange sands were preglacial in age. Later the Orange sands (Lafayette formation) were found beneath the

older drift. Fluviatile deposition spread widely by shifting drain age was the interpretation given by Salisbury, for which he presented convincing arguments.

With the founding of the University of Chicago Chamberlin resigned the presidency of the University of Wisconsin to organize a department of geology in the new institution. Salisbury accompanied his chief, as professor of geographic geology, and from the beginning in 1892 till he succeeded as head of the department in 1918, he played an indispensable part in the development and carrying on of the department. As the years went by, more and more of the administrative details fell to him, while throughout the period he taught a majority of the general, backbone courses of the department. His beginning course in physiography came to be regarded by many as the most outstanding course in the university. Fortunate indeed was the student who had it. His year course in advanced general geology came to be required of all graduate students in the department, irrespective of whatever work they might have had elsewhere. Though some entered it with reluctance, believing that they did not need it, the final verdict almost invariably was that they would not have missed for a great deal this thorough drill in the fundamentals of geology. His disconcerting but stimulating comment—"perfectly true, perfectly general, perfectly meaningless"—startled many an overconfident student and forced him to think with precision and to express himself "not so that he could be understood, but so that he could not be misunderstood." Much of the success of Chicago men in the field of geology is based on the searching, relentless driving home of facts, principles and correct methods of thinking by Professor Salisbury.

In the early years of the *Journal of Geology* when outside contributions were often scanty, Salisbury contributed various descriptive glacial studies under the heading of "Studies for Students." Among them were such topics as "Superglacial drift"; "The drift, its characteristics and relationships"; "Stratified drift," etcetera. In these, stock was taken of the most advanced knowledge of the time, much of it assembled from other sources, much of it from original observation and study—all of it well organized and presented authoritatively and effectively. Though addressed to students, the mastery of the problems and succinct presentation made these contributions models of their kind, of great value to all geologists interested in glaciers and glacial formations.

In 1895 Professor Salisbury went to Greenland as a member of the expedition which was to bring Lieutenant Peary home after two years of Arctic exploration. Several stops along the west coast of Greenland

gave opportunity to compare the existing glaciers with the former extent of glaciation. He confirmed the conclusion of Chamberlin the year before that there are considerable stretches of the west coast of Greenland without evidence of glaciation. The conclusion seemed clear that the Greenland ice-cap was not very much more extended during the Pleistocene than at present. The Labradorean ice-sheet of our continent did not have its starting point in Greenland.

North of Cape York the seaward margin of the upland in many places terminates abruptly in steep cliffs. Tiny glaciers developing where the topography favors lodgment were recognized as an undescribed type. For these Salisbury proposed the designation "cliff glaciers."

Peary's headquarters were on Inglefield Gulf and here Salisbury had abundant opportunity to study carefully the numerous high-latitude glacier tongues streaming from the ice-cap toward the sea. These high-latitude glaciers have exceptionally steep sides and the secondary structures developed by shearing and other differential movement within the ice in its descent from the ice-cap were most strikingly revealed. Debris was dragged along in zones of differential movement and the upturning of debris layers along the margins of these glaciers was minutely described by Salisbury. In some cases he found distinct superglacial moraine ridges resembling on a small scale the terminal moraines at the margins. He seems, however, to have attributed the "layering" of the ice and the debris zones largely to original stratification and but little to secondary concentration of debris by internal differential movement within the glacier in its long journey. Internal shearing in tongues of moving ice was not so well appreciated then as now.

These first-hand studies of many striking Greenland glaciers afforded the basis of much of Salisbury's masterful teaching of glacier phenomena ever after. They contributed strongly to the later textbook descriptions.

Salisbury's paper on "Terminal moraines from north Germany," published in 1888, had attracted the attention of Dr. John C. Smock, who later became State Geologist of New Jersey. One of his first acts was to "borrow" Professor Salisbury from the United States Geological Survey to undertake a detailed study of the Pleistocene formations of New Jersey. This work, starting with the field season of 1891 and continuing with some interruptions for many seasons thereafter, constituted Salisbury's most elaborate and systematic field researches. The results are set forth in a series of papers appearing in the Reports of the State Geologist of New Jersey from 1891 onward and culminating in the publication of three special volumes of the "Final report series." These were The

physical geography of New Jersey, volume IV, 1895; The glacial geology of New Jersey, volume V, 1902; and The quaternary formations of southern New Jersey, volume VIII, 1917, a manuscript long delayed in publication.

In this work Salisbury was assisted by several of his graduate students, chief of whom were Henry B. Kümmel, Charles E. Peet, and George N. Knapp. Salisbury, however, did much of the detailed work himself, and at all times kept close track of the work and tentative conclusions of his assistants, to whom he gave generous credit, in many cases making them joint authors.

In addition to mapping the glacial drift of the State with a detail and accuracy not theretofore attempted by any State survey, Salisbury's studies thoroughly established the existence of at least two and possibly three drift-sheets of greatly diverse ages. Deposits of extramorainic glacial drift had been noted by earlier geologists in New Jersey, and Lewis and Wright had traced a "morainic fringe," thought by them to be of substantially the same age as the moraine, across northeastern Pennsylvania.

The work of Salisbury and his assistants definitely established the much greater antiquity of most of the drift south of the Wisconsin moraine to which the name Jerseyian has been applied. He recognized, however, that this "extramorainic" drift, to use his own term, had a younger aspect in some localities than in others, and he kept constantly in mind the two possibilities: (*a*) That this younger phase represented a third sheet of intermediate age, or (*b*) a local commingling and reworking of the early Jerseyian drift with the addition of fresh material in Wisconsin time. On the whole he probably favored the latter view, not considering the evidence sufficiently strong to demonstrate the existence of a third sheet. Later studies by Leverett now seem to point to the conclusion that both the Illinoian and Kansan drifts occur in New Jersey, the southern portion of Salisbury's Jerseyian being the Kansan, and the part nearer the moraine being the Illinoian.

Early in this work Salisbury's attention was attracted to a peculiar form of gravel terrace, locally with pitted surfaces and mostly with kamelike fronts, which is common in the valleys of northern New Jersey. These were first and fully described under the title of "Drift deposits made under the influence of stagnant ice" (New Jersey Geological Survey, Report for 1893, pages 152-156). In the excellent general treatise on glacial geology in volume V the formation of kame terraces, crevasse fillings and related features was admirably described and illustrated

(pages 122-24). During 1893 and 1894, under Salisbury's direction, Kümmel mapped many of these stagnant ice forms in Sussex and Warren counties, as did Peet for Morris and Passaic counties. But in recent years this work of Salisbury and his assistants unfortunately seems to have been given very scanty recognition by some of the younger geologists.

The interpretation of the geologic history of the yellow gravel deposits of central and southern New Jersey provided a difficult task and the studies extended over many years. Salisbury did the reconnaissance work and Knapp most of the detailed mapping. Salisbury's hypotheses were constantly being checked by Knapp's detailed observations, and Knapp's studies were in turn directed by Salisbury's interpretations.

Various views concerning the origin of these formations have been held: (1) Marine origin, representing successive submergence up to heights marked by the upper limits of the several formations recognized, the several submergences being separated by emergences (the Maryland view); (2) subaerial origin; (3) partly subaerial, partly marine or estuarine. Salisbury rather early rejected the first view and inclined to the third. Exigencies of administration necessitating the publication of annual reports of progress, some contradictions and shifting of interpretations between earlier and later views naturally resulted. Salisbury's final views are set forth in volume VIII, in which he squarely states his belief that the deposits are partly subaerial and partly marine or estuarine, with emphasis on the subaerial rather than the marine or estuarine.

Such different interpretations by the geologists of Maryland and New Jersey had the unfortunate result, that although each survey recognized three formations of Pleistocene age, different names were applied to them, and there has been no common standard of mapping. Difficulties have, therefore, arisen in attempting to map and correlate these deposits in the intervening area of southeastern Pennsylvania and of Delaware. But it is perhaps fair to state that the work of recent observers, particularly Leverett and Campbell, seems to indicate the gradual acceptance of the New Jersey interpretation.

After 1900 Salisbury's field work was largely divided between New Jersey, where some of the work already under way was brought to completion, particularly in cooperation with others (as State reports and United States Geological Survey folios) and the Bighorn Mountains, where he directed Pleistocene studies by advanced students from the University of Chicago. But increasing administrative duties as dean of the Ogden Graduate School at the university, the organization in 1903

of a department of geography which led him gradually away from geology, and the preparation of successive text books on college geology, physiography, and later geography, occupied more and more of his time and energy as the years went by, and active geologic work suffered. Though his intense activity and tireless drive never relaxed, they became directed more and more into other channels.

The years 1904, 1905 and 1906 stand out in Salisbury's career for the appearance of the three volumes of "Geology" written jointly with T. C. Chamberlin. For some ten years the two authors had been gathering and organizing the material which was to make this series of volumes for many years to come the standard American textbook of geology. Though their literary styles were very different, by much revision they blended the more elaborate, flowing sentence structure of the one with the short, pithy statements of the other. In volume 1, on geologic processes, the work was divided by chapters; in the treatment of historical geology, Salisbury wrote the physical side of each period and Chamberlin the life development. They made an ideal team, each supplementing the other.

From 1897 till his death in 1922, Salisbury was dean of the Ogden Graduate School of Science of the University of Chicago, to the manifold duties of which important office he devoted much time. From 1903 to 1918 he was head of the new department of geography, building up probably the strongest department in that field in the country. He threw himself vigorously into the development of that department, although his own teaching remained largely in geology. On the retirement of Chamberlin in 1918, he left the new geography department, now under full steam, to become head of the department of geology. Geologic research, however, was no longer his first interest, as the zeal for discovery had gradually faded out. But as a power in administration and an unsurpassed teacher of geology he continued undiminished to the end.

Professor Salisbury loved the feeling of power. Much of the detailed drudgery of administration which would have been irksome to some men and would have been delegated by them to subordinates gave him compensating satisfaction. In this way he was especially helpful to Professor Chamberlin, saving him from much of the departmental burden and conserving his time and strength for the fundamental geologic researches which he was thereby able to carry on so uninterruptedly. In this he performed a very great service to his older colleague which was deeply appreciated and gratefully acknowledged.

Salisbury never spared himself in attending to the many duties which he willingly assumed. He worked very hard and was intense in most of

what he did. Little thought did he give to his health even when some alarming symptoms began to appear. On the last day of May he was stricken with coronary thrombosis and passed away on August 15, 1922, two days before his sixty-fourth birthday.

He was a man of strange contrasts. He had a reputation for being very gruff and short; some people felt insulted; others developed a strong dislike, but they were those who saw only one side of his nature. The gruffness was but a mask which hid the warm heart, deep human sympathy and true kindliness which were the real basis of his character. Children adored him. "The occasional invitations to his home extended to students who had earned his respect were held in higher esteem than honors awarded at commencement day." One of his chief delights was in his exceptionally wide circle of devoted friends. By them he has been greatly missed and his memory will be long revered.

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MEMORIAL OF CLAUDE ELLSWORTH SIEBENTHAL [1]

BY WALDEMAR LINDGREN [2]

To the many friends of Claude Ellsworth Siebenthal the announcement of his death at Daytona Beach, Florida, on March 1, 1930, conveyed a sense of deep personal sorrow. They felt not only the loss of one dear to them, but the too early extinction of a life which might have been active for many more years—the loss of a man who, by his unremitting devotion to his field of work, made a place for himself in the annals of our science. For nearly thirty years he had been a member of the United States Geological Survey. He was a member of the Geological Society of America (since 1912), the Society of Economic Geologists, the American Institute of Mining and Metallurgical Engineers, and the Cosmos Club of Washington. He was best known as a faithful student of the geology of the lead-zinc deposits of Missouri, Kansas, and Oklahoma, and his classic work in this region had made his name familiar to the students of ore deposits.

It is hard to realize that his quiet, friendly voice will no longer be heard in the assemblies of the men of the Federal Survey, and his presence there will be missed with special keenness. Though retiring and modest to a degree that many of us thought excessive, he possessed, indeed, a personality of genuine distinction. The writer remembers him well as he appeared when he first joined the organization—a tall, erect, but supple figure, then wearing a short, dark beard which he afterward removed; his striking appearance, together with courteous manners equally devoid of self-assertion and of shyness, bespoke the man of true,

[1] Manuscript received by the Secretary of the Society January 28, 1931.

[2] The author wishes to acknowledge the kind assistance of Dr. F. C. Wilkins, who was a devoted friend of Siebenthal and who saw much of him during his last years.

C. E. Siebenthal

good breeding. It became known in the course of time to many, in all walks of life, that his courtesy was the expression of a fundamental kindliness. Though never the conventional "doer of good," he continually and unhesitatingly followed generous impulses. Not only was he alert to perform the little observances which often mean so much; he was ready to expend energy and to exercise courage in the righting of what he considered to be wrongs. He never shrank from controversy in these or other matters—it was characteristic of him to form decided opinions and to express them rather bluntly—yet such was the influence of his inherent kindliness that he probably never made a permanent enemy. He was even known to make a friend by his manner of administering a righteous though not overgentle rebuke to a younger man with whom he clashed on the public golf course which he frequented for recreation in his later years.

Something of what has just been said is explained by Siebenthal's characteristic humor, which appeared in almost every brief conversation. For many years no scientific meeting which he attended seemed to be quite rounded off unless, rising toward its end, he gravely made some ironical comment which not merely caused a general laugh but often expressed more than many a longer, seriously intended observation. His command of countenance was such as to help the effect of surprise, yet he frankly, though quietly, enjoyed his own successful sallies. Even in the years of his declining health, his countenance, though habitually sad, was often suddenly brightened by the light of humor, as his friends take comfort in remembering.

Claude Ellsworth Siebenthal was born at Vevay, Indiana, April 16, 1869, son of John Amie and Anna McKay Siebenthal. His earliest paternal American ancestor was Francis Louis de Siebenthal, a member of an old Swiss family that emigrated from Vevey, Canton Vaud, to Indiana in 1801, with a colony that named the county of Switzerland and founded the town of Vevay in that county. From him and his wife the line of descent is traced through their son John Francis de Siebenthal, whose wife was Jeanne Marie Dufour; their son, Benjamin F. de Siebenthal, and his wife, Eliza Brown, were the grandparents of Claude E. Siebenthal.

The young man attended Indiana University from 1889 to 1891, and completed his university studies at Leland Stanford, where he was graduated with the degree of A.B. in 1892 and received the degree of M.A. in 1893. During 1889 to 1893 he served as assistant geologist on the Arkansas Geological Survey under Dr. John C. Branner, then professor of geology at Stanford. In 1896 he returned to Indiana to serve on the State Geological Survey, for which, in collaboration with T. C. Hopkins, he prepared a report on the Indiana oolitic limestone.

In 1897 he was made a fellow at the University of Chicago, where he remained three years, and while there he did a piece of work which attracted much attention—a series of relief maps of the Chicago area showing the different stages of the Pleistocene Lake Chicago.

He joined the United States Geological Survey as assistant geologist in 1901 and reached the rank of geologist in 1911. In 1902 and 1903 he assisted W. S. Tangier Smith in the field work and the preparation of the folio covering the Joplin district, Missouri. From 1903 to 1905 he was assigned to the division of hydrology and studied the geology and water resources of the San Luis Valley, Colorado, recording the results in Water-supply Paper 240, published in 1910. Later, with N. H. Darton, he made field studies in the Laramie region, Wyoming, and prepared a large part of the Laramie-Sherman folio (published in 1910 as folio 173 of the Geologic Atlas). In 1906 he again took up the study of the Joplin region, particularly in the Wyandotte, Indepedence and Muskogee quadrangles, giving his attention both to the Paleozoic formations and to the lead-zinc deposits. With many interruptions, owing to his work in connection with the annual statistical volume "Mineral Resources," he continued this investigation to 1929. The fruition of his studies in geology and ore genesis is found in his report on the origin of the zinc and lead deposits of the Joplin region, referred to in more detail below.

In 1907 he was appointed geologist in charge of the statistics from the zinc and lead smelters throughout the country and of the compilation by correspondence of the mine production of the same metals in the Central States. This connection with the division of mineral resources continued until 1925, when the division was transferred to the United States Bureau of Mines. The results of his activities are found in a large number of papers. The general lead and zinc reports were written by him until 1924, as were also the reports on cadmium that were issued after 1909. In 1917 and 1918 Siebenthal collected for the War Industries Board weekly and monthly statistics on the production of lead and zinc.

During his later years Siebenthal resumed his studies of the Joplin mining region, particularly in Oklahoma. He did a fine piece of work in preparing a contour map of the surface underlying the Cherokee shale in the Picher district, Oklahoma. In 1925 and 1926 he undertook a reconnaissance of the fluorspar districts of Illinois and Kentucky and of many lead and barite deposits of districts of Missouri outside of the Joplin region. He was at work on these subjects and on the prepartion of a geologic folio on the Wyandotte quadrangle up to the time of his retirement from the Geological Survey, June 30, 1929.

His retirement was voluntary and was due to his feeling that he was unable, because of impaired health, adequately to perform his official duties. In the hope, perhaps not very strongly held, of improvement and ultimate return to scientific work, he went to Maine that summer and to Florida in the following winter, but a rapid sinking in February brought the end, for which, although his health had been failing for years, his friends were still not generally prepared. His wife was Miss Myrtle Alice Madden, of Chicago, whom he married in 1904.

The life work of Siebenthal may be divided into three sections. The earliest part related to general geology, geologic mapping, glacial problems, building stones, and various other economic subjects. The second and largest part is recorded in "Mineral Resources," and its importance should not be underestimated. Siebenthal was one of the first to try, from about 1906 onward, to coordinate the dry tables of metal statistics with the facts concerning the ore deposits from which the metals are derived; to trace the origin of the ores treated by the smelters; and to see what proportions of the metals are obtained from the various kinds of deposits—to separate, for instance, the production derived from oxidized zinc ores from that won from the iron-rich sphalerite of the West and the purer zinc ores of the Central States. Furthermore, he endeavored to obtain the statistics of mine production by separate kinds of ore directly from the mine owners and to compare these results with the aggregate smelter production.

The pursuit of all these objects involved an enormous amount of difficult and wearisome routine work. We may well feel that too much of the time of such a man was absorbed in these pedestrian tasks, and that more of the burden might have been placed upon a clerical staff. It must be remembered, on the other hand, that the work in its pioneer stages required, for its most effective organization, the persistent efforts of a man specially qualified, not only by knowledge of the geology of many kinds of deposits and of the methods by which they were mined, but by tact and judgment. Siebenthal had these needful qualities, and the work deeply engaged his interest; he considered it a duty to put the task through and gave to it unstinted time and effort. The results justify this quiet devotion and will help to make his name remembered.

No doubt he would have accomplished more of purely scientific work had he been spared this heavy load; nevertheless his geologic work is more than sufficient to guard his fame as a research man. The Joplin folio of the Geologic Atlas (number 148, 1907; reprinted 1914), by W. S. Tangier Smith and Siebenthal, stands as a splendid monument to its authors in clear presentation of a difficult problem in ore geology. True,

they were not the first in the field, which had been investigated by men such as Arthur Winslow, E. R. Buckley, H. F. Bain, and H. A. Buehler. Siebenthal and Smith did not follow in their footsteps, however, but struck out in original paths.

Siebenthal's long investigations in the Joplin region culminated in the publication in 1915 of United States Geological Survey, Bulletin 606, entitled "Origin of the zinc and lead deposits of the Joplin region, Missouri, Kansas, and Oklahoma," a work of the highest scientific value. It is not long—only 206 pages. It would have been easy to enlarge it many times by detailed descriptions, but Siebenthal held closely to the major issues, and the result is wholly admirable. After a broad presentation of the geologic features of the Ozark uplift he explained the general relation and vertical distribution of the deposits, then entered deeply into the chemistry involved in the transportation of zinc and lead by meteoric waters and gave convincing reasons for believing that such a transportation is not only theoretically possible but actually in operation. He described the composition and content of various kinds of waters of meteoric origin, and brought out the fact that zinc and lead are widely distributed in the rocks of the region, especially in the Cambro-Silurian limestones. The mineralization of the region and the relations of the ore deposits to the Pennsylvanian shale were set forth in detail. In conclusion, he found that atmospheric waters sink from the surface into the Ozark uplift and dissolve the small quantities of lead and zinc contained in the older Paleozoic limestones. These waters descend to considerable depth, rise again under artesian pressure in the Joplin district, and deposit their load underneath the Pennsylvanian shale. The theory was logically tested in all its aspects, and adjacent regions and districts were also compared. The volume is a splendid example of the development, on the basis of ascertained facts, of a theory that will explain them. Practically, the results are of high importance because they localize the areas in which ore deposits should be expected. The book proclaims the distinguished geologist.

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MEMORIAL OF JOHN LITTLEFIELD TILTON [1]

BY DAVID B. REGER

John Littlefield Tilton was born at Nashua, New Hampshire, January 11, 1863, and died of heart failure diagnosed as coronary thrombosis in his geological classroom at West Virginia University, Morgantown, West Virginia, November 17, 1930, aged 67 years.

He was of English stock, his father, John Tilton, a merchant of Nashua, being descended from forbears who came to America about 1630, and who first settled at Saugus, now Lynn, Massachusetts. His mother, Celia

[1] Manuscript received by the Secretary of the Society January 13, 1931.

Meder, was from Maine, being likewise of early pioneer ancestors who settled at Nantucket and Marthas Vineyard. In addition to John Littlefield the family included two brothers, Dr. Frank Tilton of Boston, and Osman B. Tilton of Nashua, both of whom have passed beyond. He was married on September 4, 1890, to Ida May Hoyt, a childhood playmate of Nashua and student at Smith College. To this union was born one daughter, Besse Swinburne, who died in 1918, aged 27 years. Mrs. Tilton now resides with her brother, Dr. Samuel Hoyt, a physician of Omaha, Nebraska.

His education began in the public-schools of Nashua where his studious habits made him a medal scholar in the high school. In 1881 he entered Wesleyan University at Middletown, Connecticut, where he became a pupil of William North Rice who was then professor of geology and natural history. No more fortunate or congenial environment could have been possible for the lad, as Dr. Rice was not only a thorough lover and exponent of nature but was also a noted lecturer and writer on topics relating to evolution and religion. To this learned and reverent man John Tilton became not only a pupil but a disciple as well, and the relation never ceased as long as William North Rice lived. They met for the last time at the Cleveland meeting of the Society in 1927 when Tilton, with beaming face, presented to the aged scholar the younger fellows who had not previously known Dr. Rice.

John Tilton received an A.B. degree from Wesleyan in 1885; taught in the public schools of Niantic, Connecticut, in 1885-6; returned to Wesleyan in 1886 as a museum assistant in natural history and took an A.M. degree in natural history in 1888. Later, under the Thayer scholarship earned by the presentation of a paper on geology, he studied under Shaler and Davis at Harvard University, receiving an A.M. degree in 1895. In 1902-3 he was a fellow in the University of Chicago where he received his Ph.D. degree in 1910.

In 1888 he became head of the science department, embracing earth sciences and physics, at Simpson College, Indianola, Iowa, and so continued, with the brief interruptions above noted, until 1920. In this long and most vigorous period of his life he not only performed faithfully and well the multitudinous duties devolving on such a position in a comparatively small college but also served at times as acting dean of the college and had general charge of athletics. Other activities included summer work as a geologist of the Iowa Geological Survey from 1890 until 1920; a professorship in geology at the Macbride Lakeside Laboratory of the University of Iowa in the summers of 1915 and 1916; and

a professorship in the summer school of the same university in 1918. He was also park commissioner of the city of Indianola and a lieutenant in the Iowa National Guard, having drilled and made ready for service in the World War many of the Simpson College students. This latter work was done without assistance and without military equipment and strictly as a voluntary and patriotic duty. In addition to all these things he gave much time to the Iowa Academy of Sciences, to the Masonic Lodge and to the Methodist Episcopal Church, to all of which he was greatly devoted.

In 1920 he became associate professor of geology at the West Virginia University and in 1923 was advanced to a full professorship which was retained until his demise. From September, 1926, until February, 1927, he was acting head of the department. His contract with the university, however, involved no summer work and from July, 1921, until his death he also served as paleontologist of the West Virginia Geological Survey, his eminent fitness for this position having been recognized by the late Dr. I. C. White, State geologist.

Dr. Tilton was a member of Gamma Phi Chapter of Delta Kappa Epsilon Fraternity and of Phi Beta Kappa; Fellow, American Association for the Advancement of Science; Fellow, Geological Society of America; Fellow, Paleontological Society of America; Fellow (and life member), Iowa Academy of Sciences (president in 1907); member, Iowa Association of Science Teachers (president in 1909); member, West Virginia Academy of Science (president in 1928 and 1929); member, West Virginia University Scientific Society; member, Warren No. 53 Lodge, A. F. and A. M., Indianola, Iowa (Master in 1900); member, Scottish Rite Masons (14th degree) at Morgantown; and member, First Methodist Episcopal Church of Morgantown.

To all of these organizations, whether scientific, fraternal or religious, he gave zealous attention. In their various activities he was not only a worker but also a leader in thought. In scientific societies he was never content with mere membership and attendance but usually presented a valuable paper and seldom failed to propose and vigorously advocate the things which keep such organizations alert and alive. In the Iowa Academy of Sciences he not only served as president but was a life member as well. In the West Virginia Academy of Science he was a charter member and president; and its proceedings are replete with his scientific papers and committee assignments. Beyond all doubt this organization may thank Dr. Tilton for much of the healthy growth and scope which it has reached in the six years of its existence. Although 67 years old Dr.

Tilton showed little trace of advancing age. Both mind and body were vigorous and alert. Shortly before death he expressed the hope that he might still be able to do twenty years more of work.

It is evident from the chronicle of Dr. Tilton's life that he was both a teacher and a worker in science but the teaching viewpoint was always supreme. His original researches which were extensive, both in the field and in the laboratory, were designed if possible to bring to light new things which could be taught, either in the classroom or through the medium of the printed page. To that end it was his usual custom to make brief announcement of important discoveries, followed later by more elaborate details developed by systematic study. Such a viewpoint naturally kept him entirely outside the realm of commercial or economic geology. His State survey work was not without economic benefit to the public but it was always the benefit that could be derived by an economic geologist or mining engineer with ability to interpret for his clients the primary or fundamental work of a scientist.

In harmony with this apparently fixed objective of his life Dr. Tilton indulged in no commercial vacation work, although fully realizing that such work by other college men in similar lines often carried substantial rewards. To him a vacation was an opportunity to see and to write more geology, and to that end it was his custom to spend all possible summer or other vacation time in the field, preferably on State survey work because of the assurance that his own knowledge would be increased and that publication would also result. His intervals of relaxation were few. His last extensive trip, made in the summer of 1930 from Morgantown to the Pacific northwest coast and to southern California and the Grand Canyon of Arizona, occupied only five weeks and was planned to embrace the maximum number of geological side trips. Among these was a descent into the Grand Canyon to view the tracks of *Baropus coconinoensis* for comparison with certain Permian tracks newly discovered in West Virginia on which a posthumous paper is now presented to the Society.[2] This single excursion of a few hours, in fact, may have been the leading motive of the entire trip.

His fondness for teaching was never more forcibly illustrated than was the case about two years before his death when the suggestion was made that he would be admirably fitted to take charge of a new museum in contemplation for the university and that in addition to the considerable honor of being its first director eventual retirement would be greatly

[2] John L. Tilton: Permian vertebrate tracks in West Virginia. Geological Society of America, Toronto Meeting, December, 1930.

deferred. To this suggestion his answer was brief and courteously emphatic. He preferred to continue teaching.

In the full forty years of Dr. Tilton's teaching it is difficult to select the most important stage. At Simpson College he necessarily occupied a leading position where he was known by all and where his influence was felt in all circles of campus life. At the West Virginia University, on the contrary, he was one specialist among many and was intimately known only by the small percentage of students who entered his classroom and by the faculty where his acquaintance was general and influential. His preparation of data and exhibits for the classroom or laboratory was painstaking and complete and his attention to the individual needs of a student was proverbial. This whole instinct of cheerful service was epitomized on the morning of his death when he hurried to his classroom in order to give a few minutes to a blind student and when he was suddenly stricken in the very act of handing to this student a specimen of coal for manual examination.

The professional training of Dr. Tilton was very broad, embracing practically all aspects of geology. In Simpson College this general knowledge was all required since he taught not only all branches of geology but also physics and other natural sciences. With the Iowa Survey, also, his work was on areal geology and was broadly inclusive, involving not only the stratigraphic and structural details but also the complicated glacial sheets with which much of the State was covered. In the latter he found material for his doctorate thesis entitled "The Pleistocene deposits in Warren County, Iowa," which was a valuable contribution to the literature of the subject. In this stage of his career the discussion of the Pleistocene recurs not only in his work for the Iowa Survey but also in various papers for the Iowa Academy of Sciences to which he was a frequent contributor.

In addition to the geological reports on Warren, Madison (with H. F. Bain), Clarke, Cass and Adair counties, the Iowa Survey published for Dr. Tilton in 1920 his extensive paper on "The Missouri series of the Pennsylvanian system in southwestern Iowa." Of the latter Dr. Tilton himself, in a personal bibliography prepared at the request of the writer in 1928, says: "This is my most important report on an area in Iowa, giving the result of several years of summer work. It re-draws the geologic map of a quarter of the State and corrects errors of previous workers." In it he traced northeastward through several counties the Thurman-Wilson fault which was covered not only by the glacial drift

but also by the Dakota sandstone, and which was previously known in only a small sector along the Missouri River.

In West Virginia Dr. Tilton's work was more specialized and possibly more exacting. In the university, with certain exceptions, he mainly taught historical geology and had full charge of the paleontological collections which were indexed and reduced to systematic classification by himself and his student assistants. With the West Virginia Geological Survey his duties as a paleontologist required that he identify and describe both his own collections and those of other geologists who were engaged in constant work on the areal and stratigraphic description of many counties. His individual work included the detailed geology of Hampshire County and (with William F. Prouty) Pendleton County, and a general study of the paleontology of the Dunkard series (Permian) and Monongahela series (of the Pennsylvanian). To the baffling microfossils of these two series he devoted two seasons and much laboratory study, but most unfortunately the work was left uncompleted with the exception of certain papers on Permian vertebrates. His studies of the collections of other geologists, however, were almost entirely finished and appear with the county reports and also in separate form. With this work for the Survey the writer has been intimately familiar, having made many of the collections which Dr. Tilton studied and also having directed his work for two years when acting as head of the Survey.

Passing now from the strictly scientific aspects of Dr. Tilton's work it is in order to discuss briefly his personality and philosophy of life. His manner was gentle and obliging to an extreme. The numerous favors and requests for information with which he was constantly beset by students and younger geologists were cheerfully granted regardless of the work involved or the time required; and in such matters no person in Morgantown had more frequent occasion to call on him than did the writer. His personality was engaging and he was a pleasant companion in the field, in the office and in social affairs. His disposition, however, was sensitive and entirely devoid of joviality, and his associates soon learned that the rough jokes and banter which they delighted to give, and even to receive as an evidence of good fellowship, were not appreciated or returned in kind by Dr. Tilton. He indulged in no disparaging gossip about his professional associates on the campus or in the world at large. Whatever private opinions he may have held about men of less scholarly attainment could scarcely be forced from his lips, while on the other hand the occasional slights and discourtesies which came to him, as to all others, were received without exhibition of rancor and without attempt at re-

taliation. His home life was ideally perfect. On Mrs. Tilton he lavished a wealth of kindly affection and to the memory of his only daughter, whose loss was the controlling sorrow of his life, he bestowed an equally generous share of love.

He was a firm advocate of the theory of evolution and he was an equally firm believer in theology. In both these fundamental matters he followed closely the precept and example of William North Rice, whose kindly teachings had evidently become a part of Dr. Tilton's life. His scientific library contained Darwin's "Origin of the Species," together with Rice's "Twenty Years of Scientific Progress," "Christian Faith in an Age of Science," "The Return to Faith," and many other volumes relating either to evolution or to the reconciliation of science and religion. He himself was the author of many short papers of similar kind, published in religious journals and in the secular press, and he was always ready to express his views in the classroom, in the pulpit or before the microphone. His chosen science of geology was followed with untiring zeal and his selected avocation of scientific-religious thought was given equal devotion. Beyond all doubt the reconciliation of science and religion was measurably increased by his spoken and written words. For such a life as his the world may indeed be thankful.

The story of Dr. Tilton's life is not fully told without brief quotations from the opinions of others. In the *Zenith,* published by the class of 1914 at Simpson College and dedicated to Dr. Tilton, is the following anonymous tribute:

"We may characterize him as the specialist, yet as the versatile, the many-sided Dr. Tilton. The dean of Simpson's faculty, a quarter of a century of devoted service has left him with ripened experience, but scarcely touched by time. And how thorough the preparation which crowns his maturing powers! Medalist in his high school days; a Phi Beta Kappa scholar and Master of Arts at his alma mater; further honored with a Master's degree by Harvard University; author of many scientific papers and member of many scientific associations; he has literally left no stone unturned that he might be master of the work to which he has been called.

"All this ripe scholarship is constantly laid under contribution for every student under his tuition. The worth of his thorough preparation and the pedagogical skill with which it is employed are witnessed in the marked success of the pupils whom he has fitted for graduate studies in the higher technical institutions of the country.

"While thorough and intense in his specialized preparation for his department, Dr. Tilton is a man broad in his interest and his activities. He is one of the most public-spirited men who have been connected with the College. His best known public services are his thorough studies in the geological resources of Warren, Madison and Clark counties; his intelligent interest and

persistent endeavors which in large part made possible the Indianola Public Library; his work on the Indianola Park Commission and in the creation of Buxton Park, one of the beauty spots of Indianola; and his studies and valuable suggestions in the problem of the water supply of the city of Indianola.

"That which should stand the highest, however, in any just appreciation of the services of Dr. Tilton, is the spirit and manner in which he has wrought. Every service he has rendered has been ennobled and enhanced in its value by the spirit of fidelity and of strict scientific accuracy, by conscientious care for every least detail and by that loyal enthusiasm that glorifies all service. With full appreciation for his profound scholarship in his department and of his skill as an instructor, we may still say that his best service is himself, that teaching by life and example which ceases not to speak when text-book and problem may all be forgotten. A keen sense of honor has kept him at his appointed service while others might have used their enlarging preparation to climb to self-preferment. He has wrought with a devotion to the truth and to the service of his pupils that has lost all sight of self. His endeavor to get, and do, and give his best has been to him a religious devotement. He has wrought out his faith in daily deeds of conscientious service.

"Full well has Dr. Tilton earned his recognition in the scientific and educational world, and full well has he won a lasting place in the affections and gratitude of the many who have felt the impress of his spirit in Simpson's halls."

The following is excerpted from the account of Dr. Tilton which appeared in the *Indianola* (Iowa) *Tribune* of November 18, 1930, as written by the editor, Don L. Berry, who was a former student:

"Dr. John L. Tilton, for thirty-two years a professor in Simpson College, died suddenly from a heart attack in his classroom in West Virginia University at Morgantown yesterday, at the age of 67. He was, to my mind, one of the most useful men who ever contributed to the teaching in Simpson College. This is my feeling after having known him as a neighbor when a boy, having spent many days with him on the trail, and many nights in camp, and having been a student under him in several subjects over a period of nearly six years.

"Here was a man who was keenly abreast of all that was doing in scientific research and development. He shied from nothing that investigation revealed to be truth. He sought truth with persistent industry. With it all, he kept himself the highest type of Christian gentleman.

"His teaching came to the lives of young people at a time when new revelations often wreck or threaten Christian faith. At this period Dr. Tilton carried many over the crisis, opening to them a wider vision of the truths of science, yet leaving firm the underlying principles of their religious life. To him God was indeed truth. . . .

"I can truthfully say that Dr. John L. Tilton was one of the best men I ever knew. His industry, his high ideals, and his unselfishness were an inspiration to me during the days of boyhood and youth. That statement is sincere, not mere words of encomium. And I think many other men could say the same

of him. I think I knew him better than most of his students, yet he never permitted to me, so far as I could see, any privileges or familiarities in class room that were not given to all. I liked that. It was honest. It was fair. It was characteristic of Professor Tilton."

From the *Morgantown Post* of November 17, 1930, the following paragraph is excerpted:

"Although of a modest and retiring nature Dr. Tilton made friends readily and was one of the most popular and highly esteemed members of the University faculty. His students found him always willing to assist them in their studies. Throughout his career here he gave generously of his time and was ever ready to make interesting talks on the subject of geology. Only last Saturday afternoon he spoke from the *Morgantown Post* radio studios of Station WMMN, having for his subject 'A Permian Fishing Hike in West Virginia'."

At the brief private funeral in the home Dr. Sheridan Watson Bell, pastor of the First Methodist Episcopal Church, delivered a touching tribute which was repeated in substance to the congregation on the following Sabbath. Speaking with visible emotion of the man whom he dearly loved his remarks were characterized by the following peroration, as freely quoted from the memory of the writer:

"Think of stepping on a strange land after a long journey over an unknown sea and suddenly realizing that the land is heaven. Think of being grasped by a warm hand and instantly knowing that it is the hand of God. Think of breathing a rare zephyr and quickly sensing that it is celestial air. Think of feeling a strange revival of the spirit and gloriously comprehending that it is immortality!"

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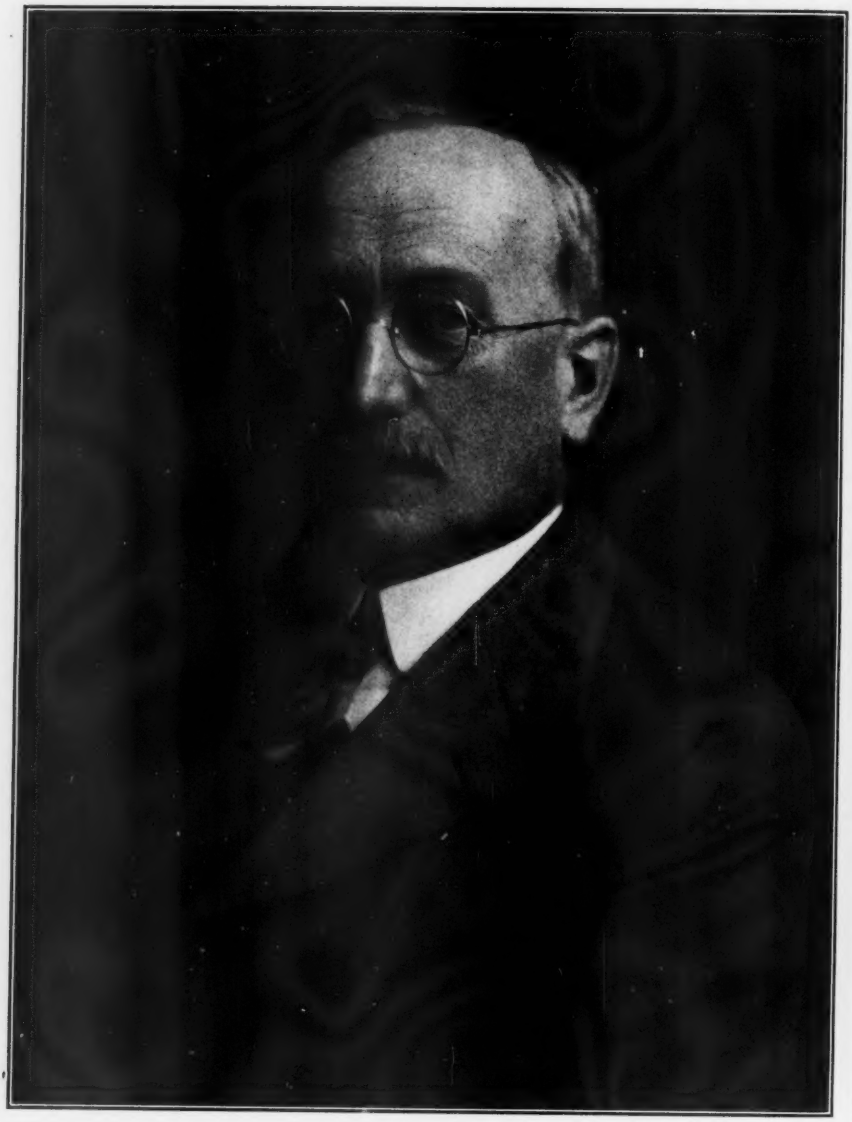

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MEMORIAL OF GILBERT VAN INGEN [1]

BY B. F. HOWELL

Gilbert Van Ingen was born in Poughkeepsie, New York, on July 30, 1869. He was descended from old Dutch families, many of whose members were talented artists. Born among the green hills of the Hudson Valley, he satisfied his inherited love of beauty by studying the beauties of nature. He thus became interested in natural history; and when, as a student at Cornell, he fell under the influence of Professor H. S. Williams, it was but natural that he decided to devote his life to the twin sciences of paleontology and stratigraphy.

Professor Van Ingen grew up in Poughkeepsie. Formally educated in a private school, he also received instruction in the use of pencil and brush from his father, who was professor of art in Vassar College; and he went to school to Mother Nature in the woods and fields around his

[1] Manuscript received by the Secretary of the Society November 23, 1930.

native town. His interest in biology proved greater than his interest in art; and when, in 1886, he went to Cornell for his university training, he planned to become a botanist. Professor Williams, however, aroused in him an ardent interest for paleontology and stratigraphy, which determined his choice of a profession, and which never flagged during the rest of his active life.

Professor Williams not only instructed him in the classroom, but also took him into the field as his assistant in his summer work and helped him to obtain a position as assistant geologist on the staff of the United States Geological Survey. In that capacity the young geologist spent most of the year 1890 and part of 1891 in research on the Carboniferous rocks and faunas of Missouri, under the direction of Professor Williams and Dr. G. K. Gilbert, who was an old friend of his father and for whom he had been named. He did not remain long with the Survey, however, but returned to Cornell as Professor Williams' assistant, transferring with him in 1892 to Yale, where he took advantage of the opportunity to study zoology under Professor A. E. Verrill. He did not receive a degree from either Cornell or Yale; but he received an excellent training for his chosen profession; for, in addition to his research work in the laboratory, he got experience in teaching and was enabled to do much field work, visiting, among other places, the then little-known Middle Paleozoic district around Moosehead Lake, in northern Maine.

In 1893 he received an appointment as assistant in paleontology at Columbia. There he remained for eight years. For the last six of these he was curator of geology; and he labored with Professor J. F. Kemp to build up the great collection of rocks, ores and fossils of which the university is so justly proud. He also served as editor of the "Transactions of the New York Academy of Sciences" and of the paleontological department of the "New International Encyclopedia." During the summer vacations he carried on field studies on the Lower Paleozoic rocks of various areas in eastern North America. In 1894 he worked with Dr. G. F. Matthew and Dr. W. D. Matthew in the Saint John district of southern New Brunswick. In 1893, 1895 and 1899 he visited Lake Champlain, went up the Hudson and Mohawk valleys in 1897, and in 1898 extended his field of investigation to western New York. The summer of 1896 he spent in an examination of the Silurian rocks and fossils of the Batesville region in Arkansas and he returned to that area again in 1905.

In 1901 Mr. Van Ingen was appointed assistant paleontologist on the staff of the Geological Survey of New York and moved to Albany where he was engaged for the next two years on several problems in the State,

especially certain ones having to do with the Potsdam and Ordovician paleontology and stratigraphy of the Champlain region and the Silurian and Devonian at Kingston in the Hudson Valley. In 1903 he married Miss Harriet Galusha, of Rochester, New York, with whom he was to live happily for the rest of his life.

Not long after his marriage he was called to Princeton as assistant in geology and curator of invertebrate paleontology. There he remained for 22 years, taking a very active part in the building up of the strong department of geology which was being erected there. He was made assistant professor in 1908 and associate professor in 1921. He acted as curator of invertebrate paleontology and stratigraphy and taught those subjects, as well as historical geology. He was an enthusiastic and inspiring teacher, both in the laboratory and in the field. He was untiring in his efforts to aid his graduate students in their researches; and they, in turn, developed an affection for him which produced an admirable *esprit de corps* among them. He was at his best when teaching in the field; and he made field instruction a vital part of Princeton's geological curriculum. None of his students will ever forget the days which they spent with him in the hills of New Jersey, Pennsylvania, Maryland, and New York. He was a jolly companion and enjoyed the boys' company as much as they enjoyed his. Many of them became his lifelong friends. In 1912 he organized and led the first of the Princeton geological expeditions to Newfoundland and he also served as leader of the Princeton parties which worked in that island in 1913 and 1914.

When, in the spring of 1917, it became evident that the United States was going to be drawn into the Great War, and Princeton offered herself to the Government for the training of Army officers, Professor Van Ingen threw himself into war work with the abounding energy which he brought to all his tasks. He was placed in charge of the instruction in map reading and interpretation in the officers' training camp that was established at the university, and was later made chairman of the academic board of the Army school of military aeronautics that was located there. His duties in the latter office were of a most exacting kind and so sapped his strength that when, during the influenza epidemic of 1918, he contracted that disease, he was never able fully to recover from it. He tried to return to his teaching and research; but it was not to be. His strength slowly ebbed and he passed away at his home in Princeton on July 7, 1925, as truly a victim of the war as though he had died on the battlefield in France.

Professor Van Ingen published only a few papers. He was so keenly interested in the work of his students and gave so much time to his teaching that he found little opportunity for writing. Some of the most important results of his researches were incorporated in the theses of his graduate students. Those which he published over his own name are given below. He had a great deal of new information partly written down at the time of his death; but none of it was in such form that it could be sent to the printer and it will have to be prepared for publication by future specialists in his field, who will complete the work which he began, but was never able to finish.

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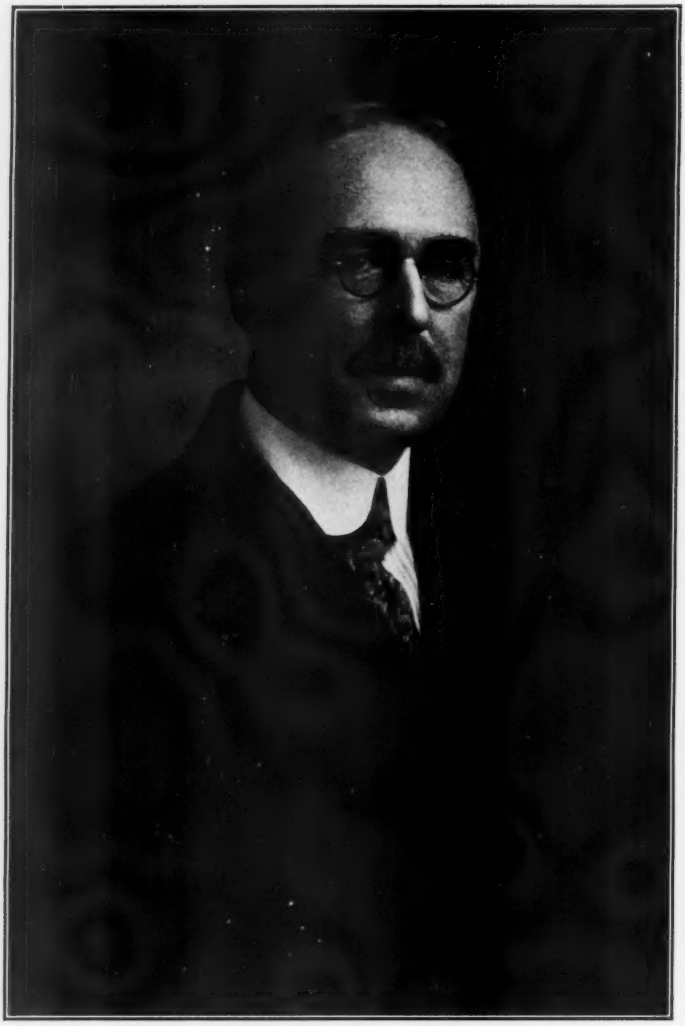

Frank A Wilder

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MEMORIAL OF FRANK ALONZO WILDER [1]

BY H. FOSTER BAIN

Frank Alonzo Wilder, who died at Abingdon, Virginia, March 7, 1930, was born at Akron, Ohio, in 1870. He studied at Oberlin College, taking his A.B. in 1892, at Yale in 1893, at the Royal Academy of Mines at Freiberg, Saxony, in 1900-01, and at the University of Chicago, from which he obtained the degree of Ph.D. in 1902. He was elected a Fellow of the Geological Society of America in 1905, was a member of the American Institute of Mining and Metallurgical Engineers, the Society of Economic Geologists, the American Society for Testing Materials and a number of other scientific and technical organizations. His professional career included teaching, geological survey work, consulting practice and the organization and direction through twenty years of an important mining enterprise. At the time of his death he had retired from business and was hoping to return to his first love, teaching, but had been prevented by ill health.

Wilder's professional work was mainly in Iowa, North Dakota and Virginia. In the first-named State he served as science teacher in the high schools at Fort Dodge and Des Moines, 1897-1900; as professor of economic geology at the State University, 1903-06; as field assistant, assistant State geologist, and finally as State geologist, 1904-06. In North Dakota he served as associate professor of geology in the State University and State geologist, 1902-03. In Virginia, to which he went from Iowa in 1906, he was president of the Southern Gypsum Company, which he piloted from the initial stage of prospecting the ground to where a large and prosperous group of chemical industries had been built up.

Wilder's work had to do with areal geology, stratigraphy, the Pleistocene formations and the geology of coal, lignite and gypsum. He was

[1] Manuscript received by the Secretary of the Society September 24, 1930.

introduced to all of these while serving as a young high-school teacher at Fort Dodge, and through associations on the Iowa Geological Survey he made the broader contacts that determined his life bent. His general report on the lignites of North Dakota [2] and on gypsum,[3] the latter report forming one of the volumes of the Iowa Survey, are truly monographic. To this day Wilder's report forms the best general summary on gypsum and the starting point for any research on the subject. For many years he kept his knowledge of this subject fresh and contributed frequent annual reviews to "The Mineral Industry" and other technical publications. These were especially informing and valuable in that they were based upon both scientific and industrial knowledge. Wilder's work on the Pleistocene is embodied in various reports of the Iowa Survey.[4] He was one of the group of hard working young men who in the nineties under the inspiration of Chamberlin, Salisbury and Calvin played an honorable part in clearing up so many of the doubts in this field of geology.

As a business man Wilder's career was crowned with success and he left as one monument of his memory a prosperous community of happy homes in what had once been a poor mountain district. He is survived by a widow, Marry Weller Wilder, his companion of many years, by two sons and a daughter and he is mourned by many friends in many States. In his death the Society has lost a Fellow who conferred upon it distinction by honest work and honest living day by day.

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MEMORIAL OF FREDERICK JAMES HAMILTON MERRILL [1]

BY CHARLES P. BERKEY

Frederick J. H. Merrill, the only son of Hamilton Wilcox and Louisa (Kauffman) Merrill, was born in New York City, April 30, 1861. He was a direct descendant of Nathaniel Merrill who came from Suffolk, England, and settled at Newbury, Massachusetts, about 1635. John Merrill, a son of Nathaniel, removed from Newbury to settle in Hartford, Connecticut, in 1657. The family was prominent in the early history of Hartford. Several members of the family removed from Connecticut to New York State at the close of the Revolutionary War and settled in Whitestown, later moving to Genessee County.

Hamilton Wilcox Merrill, the father, was born in Genessee County in 1814 and graduated from the United States Military Academy, West Point, in 1838. He served with distinction in the 2nd Regiment of the United States Dragoons in the Florida and Mexican wars, and resigned with the rank of major in 1857.

The mother of Frederick, Louisa Kauffman Merrill, was an Englishwoman, charming and cultivated, who lived in the atmosphere and experiences of the past. Her father, who was the owner of a fleet of trading vessels which plied between England, China, and America, left a considerable fortune to be divided among his four children.

The home of the Merrills when Frederick was born was 277 Fifth Avenue. Later they went to live in New Rochelle with Mrs. Merrill's sister and her husband, Judge and Mrs. Green. After some years Mrs. Merrill returned to New York, where the boy grew up in the environment of the city.

[1] Manuscript received by the Secretary of the Society March 30, 1931.

An only child, reared in the traditions of the past and altogether from a British viewpoint, Frederick developed a sensitive nature which persisted throughout his life and resulted in a mental isolation which handicapped him in making democratic contacts. Great care was taken with his training and education.

The education of Frederick continued at Charlier Institute and other schools. In October, 1880, he entered the School of Arts of Columbia College, but in 1882 he transferred to the School of Mines, devoting himself especially to the study of geology under the late Professor John S. Newberry. He was graduated with the degree of Ph.B. in June, 1885, and during the next two years, 1885-1887, was an assistant on the Geological Survey of New Jersey under George H. Cook, State Geologist.

His first assignment was the study of the coast of New Jersey, particularly with reference to the changes of shoreline and sealevels. Subsequently he made a resurvey of the Precambrian rocks of that State. In 1886 he was appointed to a fellowship in geology at Columbia College, which he held until 1890. In June of that year he received the degree of Ph.D., and spent the summer visiting the principal natural history museums of Europe. From October, 1890, to June, 1893, he was Assistant State Geologist of New York; and in December, 1890, he was appointed Assistant Director of the New York State Museum, which office he held until 1894. In June, 1894, Doctor Merrill was made Director of the New York State Museum, and in 1898, on the death of Professor James Hall, was appointed to succeed him as State Geologist.

He was director of the scientific exhibits of the State of New York at the World's Columbian Exposition in Chicago during 1892 and 1893. He was also director of the New York exhibits of the Pan-American Exposition held in Buffalo in 1901, and of the Louisiana Purchase Exposition held in St. Louis in 1904.

Financial reverses led him to resign his several important offices in 1904, when he entered private practice as a mining expert and consulting geologist. For two years he was in New York City, and then transferred his headquarters to the Southwest to be in closer touch with his private practice. Although he kept offices in New York until 1911, he lived in Nogales, Arizona, from 1907 to 1911, at which time he moved to Los Angeles, California, to remain the rest of his life.

He was field assistant for the California State Mining Bureau, from 1913 until 1916. His death occurred Wednesday, November 29, 1916, in his 55th year, in the city of Los Angeles. The immediate cause was a cerebral hemorrhage a few days before, from which he never regained

consciousness. His death was attributed to overexertion in finishing a survey of the copper camps of Arizona, made as a member of the American Mining Congress.

On September 1, 1887, he was married in old Trinity Church to Miss Winifred Edgerton of New York City, and they had four children: Louise Edgerton, born 1891; Hamilton, born 1895; Winifred, born 1902; and Edgerton, born 1904. Mrs. Merrill was a Wellesley A.B., Columbia Ph.D., specializing in mathematics and astronomy, being the first woman to receive a degree from Columbia. She took a very active part in the early steps leading to the establishing of facilities for college education for women, being on the committee of five whose preamble presented to Columbia resulted in the formation of Barnard College. Then she stepped aside from that career to take her place in family and social life for twenty years, until reverses made it seem necessary to take up problems of family support. Soon she found new interest in these added responsibilities, and succeeded in keeping a home for the children and in securing for them the advantages of a college education. A private school for girls was founded by her at Oaksmere, Mamaroneck, which prospered in her hands and attained an enviable reputation.

Doctor Merrill was first of all a gentleman with the instincts and bearing of a leisure class. He was a man of exceptional ability and had a well disciplined mind, but was not well adjusted to the trends and practices of this new country and never reached the heights of position and influence that his talents promised. He had no gift for politics, although dependent in many ways on State politicians for the support of his plans.

Even in ordinary intercourse of everyday life he was reticent and reserved, and people seldom got near to him. They respected and admired him but did not readily learn to understand and love him. Although quiet, retiring and peaceloving, he was always friendly.

Deliberate in his investigations, cautious in his scientific work, and on this account careful in expressing opinions or conclusions, he was nevertheless broadly informed and mentally very active. With a keen mind and an amazing knowledge of practical subjects, he was yet somewhat impractical, essentially an idealist, apparently living a little outside his real environment. His best friends remarked that it always seemed as though he belonged to another generation.

Both Doctor and Mrs. Merrill were especially active in social life in Albany and took great interest in the work in Saint Peter's Episcopal Church, where Doctor Merrill was a vestryman.

A devoted father and a charming man, belonging to old New York, in contact with its leaders of thought and social life, he gave a splendid inheritance to his four children, all of whom are successful and prominent. Through them the family maintains its traditional touch with the New York of a generation ago.

Doctor Merrill was an original Fellow of the Geological Society of America, a Fellow of the American Association for the Advancement of Science, and the New York Academy of Sciences; and was a member of the American Institute of Mining Engineers, the American Society of Naturalists, the American Fisheries Society, the National Geographic Society, the Brooklyn Institute, the New England Historic-Genealogical Society, the Societies of Sons of the Revolution and Colonial Wars, and the Military Order of Foreign Wars. He was a member of the following clubs: University, Reform, Athletic (of New York); the Larchmont Yacht Club; Fort Orange, Country, and Camera Clubs (of Albany); Sierra Madre (Los Angeles); and the Alpha Delta Phi fraternity.

One of his main contributions was "A guide to the study of the geological collections of the New York State Museum," published in 1898. This contains an account of the geologic formations and economic geology of New York State. It was under his direction that the geologic map of the State of New York, printed in 1901 and still in use, was compiled.

Many important articles were published in the leading scientific journals, in the reports of the New York State Museum and of the Geological Survey of New Jersey, as well as a number of contributions to magazines.

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REVISION OF THE BY-LAWS

At this point the Secretary presented the report of the Committee on Revision of By-laws, already distributed in printed form by mail to all Fellows of the Society, as follows:

Page 13. Article III, Paragraph 5

Strike out:

"approved by the Council, in the sum of five thousand dollars."

In lieu thereof insert:

in the sum of five thousand dollars or such larger amount as the Council may direct.

Strike out:

"He may deposit the funds in bank at his discretion but shall not invest them without authority of the Council."

In lieu thereof insert:

He shall deposit the funds of the Society in a bank of recognized standing and shall keep its securities in the Society's box in the vaults of a reliable bank, safe deposit or trust company. All funds in excess of the Society's current requirements shall be invested as provided for in paragraph 7 of this Article.

Page 13. Article III, Paragraph 7

After the first paragraph insert the following:

Each year at the annual meeting of the Society, the President shall, with the approval of the Council, appoint a Finance Committee, consisting of three members of the Council, to serve for one year. The Treasurer also shall be, *ex officio*, a member of this committee. Any member shall be eligible for reappointment on this committee.

When the Treasurer finds that there are funds available for investment he shall notify the Finance Committee and this committee shall recommend suitable investments to the Council for final action at its next meeting.

In addition to the foregoing specific duties the Finance Committee shall act as the general financial advisory body of the Society.

The Finance Committee shall be at all times under the direction of the Council and nothing contained in this amendment shall be construed as modifying in any way the authority of the Council to take at any time any action which it may deem necessary to safeguard the financial interests of the Society.

At the conclusion of the reading of the report it was duly moved and seconded that the revisions be approved and adopted. This was carried unanimously, without discussion.

REPORTS OF OFFICIAL REPRESENTATIVES

Charles Palache, representative of the Society on the National Research Council, has filed the following report on the service of the Council as related to geologic activities and research.

REPORT OF THE DIVISION OF GEOLOGY AND GEOGRAPHY OF THE NATIONAL RESEARCH COUNCIL

BY CHARLES PALACHE, *Representative*

The Division of Geology and Geography of the National Research Council met in Washington on May 3, 1930. The report of the chairman, Dr. Arthur Keith, presented in brief summary the progress of the 27 committees under which the work of the division is carried on, and following his report most of the committee chairmen reported orally the gist of the work of their respective organizations, the mimeographed reports of each being in the hands of the members of the division. Despite the speed necessary to cover so large a program in one day's meeting, a clear picture of the activities of the division was presented and your representative left the meeting at the end of the day deeply impressed by the wide scope and the importance of the work being carried on by the division and of its value as measured by the results obtained.

In view of the full summary of the previous annual meeting presented by Dr. Bucher in the Bulletin for 1930, volume 41, pages 33 to 41, it is unnecessary to report on more than a few aspects of the division's work, particularly as the annual report, soon to be issued, is available to all who are interested.

The report of the chairman of the Committee on Batholiths, Dr. F. F. Grout, was of outstanding importance. Besides giving a list of some 24 investigations of batholithic problems now going on in the field there is presented a critical analysis of the mechanics of intrusion of batholiths which has been widely distributed to workers as a basis for criticism and suggestion. This analysis emphasizes particularly points on which there is most divergence of opinion and raises many questions, answers to which are needed. The report should be in the hands of all workers in the field of igneous geology.

Dr. Grout also stated that the chemical laboratory for rock analyses established at the University of Minnesota was in operation. Funds for its operation for five years have been guaranteed by the Rockefeller Foundation and Dr. Ellested has a new laboratory for the work equipped by the University. Although intended primarily for analysis of materials which will elucidate the batholith problem, it is not confined to this

field. It is hoped that sufficient work will come to the laboratory to render it self-supporting.

The Committee on the Measurement of Geological Time by Atomic Disintegration reported through the chairman, Dr. A. C. Lane. Besides giving a full summary of the literature of this subject appearing during the year past, the report gives the final results of the elaborate investigation of the Kolm carried on with funds raised by the committee. The age indicated by this research for the top of the Cambrian is 440 million years, a figure believed to be subject to an error of less than 10 per cent. There is also an account of the uraninite deposit at Wilberforce, Ontario, and of the program of investigation of this first-class pre-Cambrian material.

The report of Dr. T. W. Vaughan for the Committee on Submarine Configuration and Ocean Circulation contains the table of contents of a paper extending to over 130 pages, reviewing the work in the field of oceanography of individuals and organizations in all parts of the world. It is sincerely to be hoped that publication in permanent form will be secured for this important series of summaries by Dr. Vaughan.

A distinctly new development of the work of the division during the year was in the direction of financial aid for research. This was in two forms, grants-in-aid and fellowships.

The grants-in-aid fund was made available by the National Research Council and was announced in the summer of 1929. A committee in charge of this fund was at once organized and in the first year of its activity received applications for grants for fifteen projects. Of this number ten have been granted in full or in part, totaling $10,625. The following outline of the projects aided shows the nature and wide range of work promoted by these numerous grants which ranged in amount from $200 to $4,000.

Name *Institution* *Project*

WILLARD BERRY, Ohio State University

For continuation of study and investigation on Tertiary fauna, especially foraminifera of Peru.

FRANK F. GROUT, University of Minnesota

Investigations to determine the value of random samples of rocks.

EDWIN T. HODGE, University of Oregon

Structure of the Cascade Mountains in Oregon.

PRESTON E. JAMES, University of Michigan

The regional geography of Rio de Janeiro, Brazil.

LEWIS B. KELLUM, University of Michigan

The geology and flora of the San Carlos Mountains, Tamaulipas, Mexico.

RALPH L. LUPHER, California Institute of Technology
Studies on the paleontology and stratigraphy of the central Oregon Jurassic deposits.

JAMES B. MACELWANE, Saint Louis University
Seismological investigations, involving establishment of two seismological stations at Little Rock, Arkansas, and in Kentucky or Tennessee.

EDWARD L. TROXELL, Trinity College
Research in vertebrate fossils from the Wasatch formation, Big Horn Basin, Wyoming.

EDWARD WATSON, Johns Hopkins University
Laboratory work on igneous rocks of the San Carlos Mountains.

J. M. WELLER, State Geological Survey, Urbana
Paleophysiographic conditions of the Pennsylvanian period.

The fellowships were established by a gift of $5,000 by Mrs. J. J. Storrow. The gift was announced in Science in January and applications were invited. Forty-six applications were received for the four fellowships offered. The committee was unanimous in the selection of the four men named below but regretted that the funds at their disposal were not much larger in view of the fine quality of many other applicants. They are of the opinion that they could make profitable use of a fund of at least $20,000 for this purpose.

H. J. FRASER, Harvard University Ph.D. 1930.
Relation of rock permeability to ore deposition.

NORMAN HINCHEY, Harvard University candidate Ph.D.
Paleontology and stratigraphy of the Saint Louis formation, Mississippi Valley.

RALPH L. LUPHER, California Institute of Technology candidate Ph.D.
Paleontology and stratigraphy of Jurassic of central Oregon.

JEROME S. SMISER, Princeton University candidate Ph.D.
Identification of echinoid fragments in oil-well cuttings.

It is certainly much to be hoped that means will be found to make these fellowships permanent and to increase the amount available for them.

ANNOUNCEMENT OF THE GEOLOGIC FACILITIES OF THE LIBRARY OF CONGRESS

BY ALFRED C. LANE

The Library of Congress is the great national library. It does not duplicate the collections of the Smithsonian Institute in general and, in fact, much of the Smithsonian material is housed in the Library. It, however, goes far beyond the Smithsonian. It receives or wishes to receive all public documents. It does obtain files of most of them. How-

ever, once in a while there will be a special report which it will miss. Not infrequently these are of especial scientific value. It is well, therefore, that such reports should be given or that notice should be given so that the Library may obtain them. For instance, a very interesting series of reports to the geologist on the Honolulu water supply which I sent had not been received. Moreover, it is not possible for the Geological Survey or the Bureau of Mines to cover all the literature which the geologist occasionally wishes to see if he wishes to keep in touch with the international march of science. However, the field that is not covered by these libraries and by public documents is relatively small. With a relatively small amount of money the collections might substantially include all the scientific literature. The ideal should be to have in Washington copies of every book that a scientific man might ever need to consult.

It is not possible to endow a public department library, but the Library of Congress has its own trustees and quite apart from the appropriations for its support from Congress can receive donations of books and of money to buy books. Indeed there are already endowments of professorships such as the professor of aeronautics whose duty is not merely to see that its collections in aeronautics continue to be unrivaled in the world, but also to help to make them accessible and in every way to help the cause of research. In this direction, it might well be that geologists or some special branch of geology like petroleum geology, mining geology, or seismology could find someone interested who would endow a professorship to make that field uniquely well covered.

There is another field in which I have found myself of use as consultant. A man finds an unfamiliar scientific word which is not in the dictionary and wants to know the exact circumstances under which it was first used. Here the Library of Congress may be of real service and in connection with one word suggested to me by Blackwelder, I found that the Library did not have the original work in which it was first introduced to science. The original work was promptly ordered for me and I was able to send him photostats of a couple of pages which contained the first scientific use of the word Iastruga. Again, it is now possible at a cost less than copying by typewriter to have photostats of a couple of pages of any book prepared and sent. If the matter is commercial, or one doesn't wish to wait until after Congress is served, arrangements are made for a prompt private service at something like 30 cents a page, so that if one knows just what is to be photostated, one can get prompt service. Here at times the consultant in science may be of great as-

sistance in picking out the part of a work which he knows to be most desirable.

The use of a consultant in science would be especially great to men engaged in research who are in the smaller and more isolated positions, such, for instance as Professor William Morris Davis in the University of Arizona. It must often be that the needs of the students have the first call upon the funds of an institution and those of a teacher engaged in research must be secondary. In this case, the Library of Congress may be invaluable, for by the system of interchange among the various libraries, most books in the Library of Congress can be sent to local libraries to be consulted.

Not only that, but the Library is prepared to send duplicates of its cards for a nominal cost—about a cent apiece. Some of the larger libraries have all these cards. Thus one can get a foundation of a bibliography. Moreover, one might own all the cards on a given subject.

It has been suggested that material like ours might well help to give the authorities in classification in the subdivisions of our field, especially in the extension and subdivision of the present classification, and in solving such knotty questions as to whether geophysics is geology or physics!

I enjoyed my appointment by the Librarian Herbert Putnam, and my association with Lawrence Martin, head of the division of maps, and A. P. Brigham, the consultant in geography. In fact, all the Library staff are interesting people to meet.

It might be well also to have a consultant in Canadian literatures and history, who could help not only Congress, but the diplomatic staff and others in Washington to find out about Canada. This would be an ideal position for a professor on leave or retiring from Toronto University.

ANNOUNCEMENT CONCERNING SIXTEENTH INTERNATIONAL GEOLOGICAL CONGRESS

BY W. C. MENDENHALL

Since the acceptance by the 15th International Geological Congress at its Pretoria meeting in the summer of 1929 of the invitation of the geologists of the United States to hold the 16th Session in this country, plans for that session have been gradually taking form. An Organization Committee of about thirty geologists in the United States has been created in accordance with the Rules of Procedure, adopted at the Brussels Congress. Under these rules, the Organization Committee is responsible for all preparations made in the host country for the entertainment of the Congress that is to meet in that country.

The Organization Committee has named June 11, 1932, as the date for the opening of the technical sessions and the place as Washington, D. C., and has issued a first circular indicating the preliminary organization, and an outline of excursions and topics for consideration. It has chosen officers including a Chairman, a Treasurer, a Secretary and Assistant Secretaries. It has created appropriate sub-committees including an Executive Committee, a Petroleum Committee, a Program Committee, an Excursion Committee, and a Finance Committee.

The Executive Committee performs the functions of the Organization Committee during the intervals between the meetings of the larger Committee, these meetings being held about twice annually. The Excursion Committee has laid out a series of excursions including a shorter group to be held prior to the Congress in the eastern half of the United States, and two long transcontinental excursions to follow the technical sessions. It has appointed leaders for these excursions and local chairmen at strategic points who are making the necessary local arrangements. Costs are being studied and every endeavor is being made and will continue to be made to keep these costs as low as is practicable in order to make participation in the excursions possible to overseas delegates. The Organization Committee has adopted The Petroleum Resources of the World as a major topic for discussion at the Congress, and for monographic treatment. This topic is comparable to the "Coal Resources of the World," the "Iron Ore Resources of the World," and the "Gold Resources of the World," the subjects of monographs prepared by previous congresses. The Petroleum Committee will be responsible for the petroleum portion of the program and for the preparation of the monograph.

The Program Committee is responsible for other portions of the program. It presented in the first circular a tentative list of ten topics on which discussion was specially invited. It has studied responses to this circular including comments and offers of papers upon the proposed topics and suggestions for additional topics, and has now prepared a revised and shorter list which will be published in the second circular.

The Finance Committee has thus far been inactive because it has been felt that it is premature at present to enter upon a campaign for the collection of funds from private sources for the general expenses of the Congress and for the reduction of costs to delegates in this country. The Secretariat meanwhile, however, has explored the possibility of securing Government grants for administrative expenses of the Congress and the publication of its proceedings. Provision is made in the Interior Department Appropriation Act for the fiscal year 1932 for the publication

of guidebooks and for the preparation and publication of a new geologic map of the United States on a scale of 1:2,500,000. It is hoped that this map may be available when the Congress meets in Washington in 1932. With the cordial support of the State Department, a budget has been presented and approved by the Bureau of the Budget which provides $50,000 for administrative costs of the Congress, and $60,000 for the publication of the Compte Rendu and of a monograph on the Petroleum Resources of the World. A resolution (House Joint Res. 474) authorizing the appropriation of these funds has been introduced in the House of Representatives. It is impossible at this time to predict the action that will be taken upon it.

The officers of the Congress are in communication with the officers of the Pacific Science Congress to be held in Vancouver, B. C., in May, 1932. It is hoped that arrangements can be worked out whereby overseas geologists primarily from the Pacific region who may desire to attend the Pacific Science Congress, may also find it possible to attend the 16th International Geological Congress and to participate at least in the westbound portion of one of its transcontinental excursions.

ADDRESS OF WELCOME BY SIR ROBERT FALCONER

Sir Robert Falconer, President of the University of Toronto, was in attendance at this opening session and addressed the Society, extending the welcome of the University of Toronto to the use of its rooms and accommodations for the various sessions scheduled by the Geological Society of America and the affiliated societies.

Mr. President, Ladies and Gentlemen:

Although my words will be very few, I beg to assure you that the welcome they convey will be by no means formal. The university has received you this morning, and will continue to show you hospitality while you are here, with the greatest of pleasure.

It is now a good many years since the Geological Society met in Canada, and especially in Toronto. We have had gatherings of many societies from the United States; some of you may have been here a few years ago when the American Association for the Advancement of Science met here, and we are always pleased to have our friends from across the border with us. In the matter of science the communion interest is, of course, obvious. Barriers may be said hardly to exist, and particularly, I should suppose, in geological sciences and the allied sciences. The unity of this continent is apparent. Geologists on both sides of

the line have similar problems, in many cases the same problems, and know one another intimately. Therefore, in coming here today, you are coming to those who are your friends and to those bound to you by researches into problems which are your problems as much as they are ours.

I do not wish to detain you any longer by emphasizing the commonplace as to the way in which your science contributes to our peoples in regard to their industrial advance. I merely say that it is the highest aims which we pursue in common; that is to say, in the advancement of science and the discovery of new knowledge, we are, as universities, one, and we form a commonwealth of the intellect and of the spirit to which I believe there is nothing superior for the development and progress of the human race.

I wish you, therefore, Mr. Chairman, ladies and gentlemen, every pleasure while you are here in Toronto. I am sure our committee has done everything they can for you and will put everything at your disposal.

At this point President Penrose relinquished the chair of presiding officer, to Past-President Arthur Keith.

Session for the Presentation of Scientific Papers

Titles and Abstracts of Papers

Age of the Maroon and Weber in Central Colorado

by David White

(*Abstract*)

Confirming the presence, reported about 45 years ago by Lesquereux, of Permian plants in the red beds (Maroon) near Fairplay, Colorado, and the discovery later, by the author, of Permian floras in the Manzano of northern New Mexico and in the Maroon formation of the canyon of the Arkansas River below Salida, Colorado, a reconnaissance paleobotanical examination of the Permo-Carboniferous of the central Rocky Mountain region, Colorado, discloses floras characteristic of the Permian ranging downward nearly to the base of the Maroon, 3,000 to 8,000 feet thick in the sections examined in this region, while Pennsylvanian plants are found to range nearly to the top of the underlying Weber. The discovery of additional plant-bearing beds in the section is needed for closer definition of the Pennsylvanian-Permian boundary which in central Colorado appears, however, to lie near to, if not slightly below the base of the red beds and probably not far from a zone of blue, more or less nodular, alga-bearing limestone carrying *Fusulina* and other marine fossils.

The plants at or near the base of the Weber in several sections indicate deposition of the earliest Pennsylvanian sediments in this region in middle or

early Pottsville time, showing that the post-Mississippian orogeny in the Rocky Mountain region was essentially synchronous with that in the Appalachian trough and in eastern Canada.

RELATIVE AGES OF THE IOWAN AND WISCONSIN DRIFT-SHEETS

BY GEORGE F. KAY

(*Abstract*)

The relative depths of leaching of calcium carbonate in similar materials, similarly situated topographically and climatically, have been determined within the Iowan and Wisconsin drift areas of Iowa. The results indicate that post-Iowan time has been approximately only twice post-Wisconsin time.

The Peorian loess, which separates the Iowan drift-sheet from the Wisconsin drift-sheet, apparently is related closely in time of deposition to both these drift-sheets and was deposited during a comparatively short interval.

The close relationship in age of the Iowan and Wisconsin drift-sheets does not warrant the inclusion of these two stratigraphically distinct stages in one stage to which the name Iowan or Wisconsin might be given. There would seem to be ample reason, however, for including the Iowan, the Peorian and the Wisconsin as ages in one epoch of the Pleistocene period. It is proposed to name this epoch the Eldoran epoch. The deposits of the Eldoran epoch constitute the Eldoran series. In the vicinity of Eldora, Hardin County, Iowa, the three stages of the Eldoran series—the Iowan drift, the Peorian loess and the Wisconsin drift—have been mapped as distinct formations.

In a revised classification of the Pleistocene soon to be published, four epochs (series) will be introduced, the youngest of which is the Eldoran. The other three epochs (series) are Grandian (oldest), Ottumwan, and Centralian. For the subdivisions of the epochs (series) all the names of the glacial and interglacial ages (stages) now used in our present classification will be retained.

LIMITATIONS IN THICKNESS OF BATHOLITHS

BY ALFRED C. LANE

(*Abstract*)

While there seems no limit to the coarseness of grain in pegmatites, granite massifs rarely run much over 8 millimeters in uniform grain. Such uniform grain when determined by loss of heat or mineralizers, not cataclastic nor due to devitrification, should be proportional to:

1. The power or readiness of crystallization, depending on the composition, including mineralizers;
2. The linear scale of the phenomena, that is, the thickness of the intrusion;

and inversely proportional to the square root of:

3. The ease of diffusion (the diffusivity), and
4. The difference of conditions (temperature) between those of the country rock and those of crystallization.

Now assuming that in granites of similar composition the power of crystallization does not vary greatly (in c. g. s. units it is antilog -5 ± 1), nor the rate of diffusion $(0.07)^2$, since the difference in temperature can not well be over $(28)^2$ in degrees centigrade, limits in size of grain imply limits in size of intrusion. Pegmatites crystallize under conditions not much above those of the encasing rocks, and hence are coarse, but deep-seated granites, for which the conditions of crystallization are not far from those of the country rock, tend to occur in lit par lit injections, while the large granite quarry massifs are at relatively high levels.

Wherefore, batholiths are likely to be partly exposed phacoliths, etcetera.

A sial layer of hypidiomorphic crystallized granite 10 kilometers thick is doubtful. Its grain should be about 2 centimeters—that of some phenocrysts.

ALLUVIAL FAN OF POTOMAC RIVER

BY MARIUS R. CAMPBELL

(*Abstract*)

All previous publications dealing with deposits of the oldest gravel on the Coastal Plain of southern Maryland and northern Virginia have treated them as of marine origin and have gone so far as to fix the margin of the sea back of Washington at altitudes ranging from 300 to 500 feet, but no actual beach has been described and no criteria have been given by which such beaches may be recognized and identified. The present paper endeavors to show that no conclusive evidence of marine conditions has been presented or can be found in the field, and that the determination of such an origin is based merely upon an assumption. Many facts are given in support of the contention of the present writer that the material was deposited on the land in the form of an alluvial fan, laid down by Potomac River; and at the time it was deposited sealevel was relatively 90 feet higher than it is today and the beach was located in the vicinity of Williamsburg, Virginia, instead of Washington, D. C. The surface upon which the fan was built sloped toward the south and this slope was the deciding factor in determining the great southward deflection of Potomac River and the lesser one of James River at the Fall Line. The author's concept of the Sunderland formation and terrace is that it is not a distinct formation or a terrace and that the conditions at Charlotte Hall—the type locality—and elsewhere need a new interpretation.

Brief remarks were made by Messrs. N. H. Darton and George W. Stose, with response by the author.

NEW LIGHT ON THE SO-CALLED PEORIAN INTERGLACIAL EPOCH AND THE IOWAN-WISCONSIN GLACIAL SUCCESSION

BY MORRIS M. LEIGHTON

(*Abstract*)

This paper redescribes the essential features of the Farm Creek type Pleistocene section, east of Peoria, Illinois, and marshals the evidence of a wide area to show that the so-called Peorian Interglacial Epoch was not truly

interglacial, that the Iowan ice-invasion was the initiation of the Wisconsin series, and that the classification of American drift-sheets is fourfold. A reclassification of the Wisconsin series is suggested.

Brief remarks were made by Prof. George F. Kay.

ATLAS MOUNTAINS OF MOROCCO

BY ANDREW C. LAWSON

(*Abstract*)

The Hercynian Mountains, extending over a very much larger region than the Atlas, were reduced to a peneplain on which were spread the continental fanglomerates, red beds, etcetera, of the Permo-Trias. In a geosynclinal depression of this veneered peneplain there were deposited great thicknesses of Liassic, Jurassic, Cretaceous and Eocene marine formations. At the time of the Alpine revolution about the end of the Eocene, the collapse of this geosyncline by compressive stress gave rise to the Alpine Atlas. By the end of the Tertiary the latter had been reduced to a past-mature hill range and the surrounding country to a peneplain. The rejuvenation of this hill land into the present Atlas is due to two distinct movements: A broad arching in at least two stages which lifted the peneplain near the mountains to about 1,200 meters above sealevel; and a sharp orogenic upthrust, between marginal faults inherited from the preceding cycle. The degradation of the upthrust mass and consequent loss of load induced farther rise by isostatic adjustment. The depressions flanking the range are explained as due to withdrawal of material in depth to compensate the range for its loss of load.

At this point, 1 p. m., the session adjourned for luncheon.

SESSION OF MONDAY AFTERNOON

The afternoon session was opened at 2:20 o'clock, in Room 22, Mining Building, with Vice-President Nelson H. Darton in the chair.

TITLES AND ABSTRACTS OF PAPERS

EXPERIMENTS ON THE FORMATION OF WIND-FACETTED PEBBLES

BY WALTER H. SCHOEWE

(*Abstract*)

Experiments conducted by Kuenen, a Dutch geologist, in 1928 tend to prove that wind-facetted pebbles are produced by variable winds and that the original shape of the base of the sand-blasted pebble is the chief factor controlling its final shape. Since the conclusions reached by Kuenen are in direct opposition to those held by most English and American geologists, the writer undertook to carry on experimental work on the artificial formation of wind-facetted pebbles.

The experiments conducted by the writer demonstrated that: (1) Einkanter, dreikanter and roof-shaped forms can be formed by variable winds from models having bases of definite shape, (2) einkanter and triquetous forms can be formed by constant winds, that is, winds coming chiefly from one or from two opposite directions irrespective of the shape of the base of the model, (3) models supported on a smooth, hard floor become undermined, whereas those surrounded by sand develop inclined facets, (4) faces parallel to the sand blast suffer practically no abrasion, (5) the rate of abrasion on faces sloping 30 degrees is about one-third as great as on faces inclined at angles of 60 degrees and 90 degrees, (6) selenite cleavage fragments or crystals are good negative criteria of wind action, and (7) in the incipient stages of facetting, two facets instead of one are developed.

The final conclusions reached by the writer in regard to the formation of wind-facetted pebbles are as follows: (1) The shape of the base of a pebble and variable winds are controlling factors determining the final wind-facetted form under the conditions postulated by Kuenen, (2) Kuenen's assumptions are improbable and therefore natural wind-facetted pebbles are not formed as believed by him, (3) the shape of the base is not a controlling factor in the development of forms made by constant winds, (4) the triquetous or Brazil-nut type represents the final end-stage in the development of wind-facetted pebbles, and (5) most wind-facetted pebbles are made under conditions of constant winds.

DISTRIBUTION OF ORGANIC MATTER IN RECENT SEDIMENTS[1]

BY PARKER D. TRASK AND HARALD E. HAMMAR

(*Abstract*)

The organic content of recent sediments is estimated most conveniently from total nitrogen. The ratio of organic carbon to nitrogen in modern deposits does not vary greatly from 8.4; and if the ratio of organic matter to organic carbon is similar to that for soils, namely, 1.7, the organic content would be about 14 times the nitrogen. Nitrogen has been determined on more than 1,500 sediments from all parts of the world. The range in recent marine sediments is from 0.01 to 0.56 per cent, which corresponds to 0.1 to 7 per cent organic matter. The organic content of the deposits of the open ocean is low. The average quantity of nitrogen in the sediments of the South Pacific is 3 parts per 10,000, of the South Atlantic, 4; North Atlantic, 6; North Pacific, 8; and the Antarctic diatom belt, 11 parts. The organic content of the deposits near continents and large islands is much greater than in the open ocean. The quantity of organic matter in near-shore sediments depends both on the supply of organic matter in the overlying water and the configuration of the ocean bottom. It is low on submarine ridges and high in depressions.

[1] This paper contains preliminary results of an investigation on "The Origin and Environment of Source Sediments," listed as Project 4 of American Petroleum Institute Research. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by Mr. John D. Rockefeller. This fund is being administered by the Institute with the cooperation of the National Research Council.

Near-shore areas rich in organic matter and the maximum quantity of nitrogen in the sediments in parts per 10,000 are: Abyssal deeps of Bering Sea, 37; lower part of continental slope off western North and South America, 40; Channel Islands region of California, 56; Gulf of California, 53; Pamlico Sound, 37; Florida Bay, 41; Gulf of Maine, 28; Lake Maracaibo, 47; Gulf of Guinea, 32; Black Sea, 36; Baltic, 29; East Indian Archipelago, 36; and abyssal deeps adjacent to Japan, 38. Poor near-shore areas are: Alaskan and northwest Canadian Arctic, 17; Davis Strait, 9; continental platform off Washington, 12; eastern South America from Cape Horn to the Orinoco Delta, 13; Gulf of Mexico, 11; Red Sea, 4; waters around Great Britain, 8; off Spain, 6; Mediterranean, 14; off Madagascar, 4; and off Antarctica, 8.

Read by the senior author.

ROCKY MOUNTAIN STRUCTURE IN ALBERTA

BY OLIVER B. HOPKINS

(*Abstract*)

The Rocky Mountains and the adjacent foothills consist of a series of elongate west-dipping blocks which override each other progressively from west to east. These overthrust blocks are due to compressive forces acting in an easterly direction and have resulted in a very material shortening of the earth's segment in this area, probably amounting to as much as 25 miles.

Although some folding is present, it is generally subsidiary to faulting. Folding, however, becomes more conspicuous in the western section of the mountains and the northern part of the foothills. Deep drilling on what appears to be normal anticlines of the foothills has shown that they are either large drag folds of superficial nature or folds that have been thrust-faulted on their eastern limb to such an extent that the surface fold no longer rests on its underground continuation but has been moved thousands of feet, if not miles, to the eastward. Both the mountains and the foothills are believed to have moved eastward on great sole faults, offshoots of which come to the surface at intervals to cut the areas into a number of overthrust blocks.

COLUMBIA RIVER FAULT-SCARP

BY EDWIN T. HODGE

(*Abstract*)

Evidence in support of a probable fault on the north side of the Columbia River is briefly summarized below.

A smooth, uninterrupted structural north dip-slope extends for 20 to 50 miles northward to and across the Columbia River and abuts against a scarp. This scarp is a bold, steep, smooth wall whose south face extends in almost a straight line for 80 miles.

The north dip-slope is so regular that, viewed back from the river, its canyon can not be seen and the slope seems to continue to the very base of the scarp. Excellent cross-sections of the north dip-slope are provided by the John Day and Deschutes rivers, and cross-sections through the scarp by

several canyons, and the structural evidence in each precludes the possibility of the scarp or the benches at its foot being due to other causes. These same cross-sections prove that the general north dip extends to the fault-plane and continues northward in the beds of the scarp or north block.

The large mosaic blocks caused by the fracturing of the south block and the unbroken north edge of the south block where dragged along the fault-planes were bent with the result that the "benches" on the north side of the Columbia River show a greater degree of folding and tilting than do the beds of the scarp itself. The axes of about a dozen small warps are found on the north dip-slope and mosaic blocks and these may be traced to the fault-plane where they end abruptly. In addition the strong major synclinal fold which strikes northeast-southwest through The Dalles ends abruptly against the fault-plane. The fault is a split-fault, with the greatest movement near the center and none at either end.

The fault is made more probable by the presence of triangular facets between Avery and Maryhill and just east of Roosevelt, and by the smooth plane scarp face. The fault-zone itself can be located just above Maryhill.

The fault is parallel with three asymetrical folds found farther south. Four associated minor faults split off from the main fault and extend westward on the north side. North of the scarp these faults repeat in reverse position the features exhibited by the main fault.

Further evidence of the fault is afforded by young lava flows, whose source is the fault-zone.

Evidence is given to show that the Columbia River is not an antecedent stream. On the contrary, it is a consequent stream from Umatilla to Rowena, and a superimposed stream across the Cascade Mountains from Rowena to Portland.

GEOLOGY OF THE VENTURA QUADRANGLE, CALIFORNIA

BY PAUL F. KERR, HUBERT G. SCHENCK AND SIEMON MULLER

(*Abstract*)

Sedimentary deposition of rocks exposed at the surface of the Ventura Quadrangle began in Upper Cretaceous time and has continued ever since with little interruption. The sum of the thickness of all formations mapped amounts to about 43,600 feet, divided according to system as follows: Cretaceous 1,500 feet, Tertiary 37,400 feet and Quaternary 4,700 feet. Tertiary formations mapped include: 4,300 feet Middle and Lower Eocene; 5,500 to 7,600 feet Upper Eocene (Téjon formation); 5,500 feet Oligocene (?) (Sespe formation); 5,000± feet Miocene (Vaqueros, Rincon, Modelo and Santa Margarita (?) formations); 14,580+ feet Pliocene (Pico formation and Pico claystone). The Quaternary contains thick Pleistocene marine deposits which have an interesting history of deformation and bevelment.

Intense deformation has resulted in faulting and folding of several types. Structures and formational units have been mapped on a scale of 1/31,250 with the aid of aerial photographs.

Structures indicate a complex pattern of movement. The principal faults indicate a release of pressure from inland toward the ocean. Much movement appears to have taken place since the beginning of the Pleistocene.

Large areas of overturned strata form parts of the Santa Ynez Mountains. Association of these with normal sections provides further criteria of movement from inland toward the ocean.

A section on the oil resources of the Ventura Quadrangle written by F. W. Hertel is to be combined with the geological discussion when the paper is published.

Presented by the senior author.

REVERSAL IN DIRECTION OF VERTICAL COMPONENT MOVEMENT ALONG FAULTS

BY JOHN P. BUWALDA

(*Abstract*)

Not merely does the direction of movement on faults sometimes change somewhat during successive displacements, but the direction of the vertical component of displacements is occasionally reversed. The result is that a block may stand higher than a neighboring block at one time and later sink below it. Examples demonstrating this fact are cited from the Pacific Northwest, central California and Colorado plateaus.

Read by title in the absence of the author.

ADDRESS OF THE RETIRING PRESIDENT OF THE MINERALOGICAL SOCIETY

At 4 o'clock the joint session arranged with the Mineralogical Society was called, Vice-President Herbert E. Merwin, retiring President of the Mineralogical Society of America, taking charge of the session and presenting an address entitled "Some associations of ore minerals."

At the conclusion of this address the additional papers listed for the joint session were presented.

TITLES AND ABSTRACTS OF PAPERS

EXPERIMENTS WITH SPHALERITE-CHALCOPYRITE INTERGROWTHS

BY G. M. SCHWARTZ

(*Abstract*)

Several geologists have suggested that inclusions of chalcopyrite in sphalerite should be subjected to heat treatment such as has been successfully applied to several other intergrowths. The following experiments have been made:

No.	Source of specimen	Temperature	Time	Cooling
1.	St. Kevin district, Leadville, Colo.	200°C.	24 hours	Cooled in air
2.	St. Kevin district, Leadville, Colo.	300°C.	90 hours	Cooled in air
3.	Greenback mine, Leadville, Colo.	300°C.	22 hours	Quenched in water
4.	Moyer mine, Leadville, Colo.	400°C.	70 hours	Quenched in water
5.	Greenback mine, Leadville, Colo.	550°C.	44 hours	Quenched in water
6.	Moyer mine, Leadville, Colo.	600°C.	114 hours	Quenched in water
7.	Same as 6.	650°C.	72 hours	Cooled in air
8.	Greenback mine.	600°C. ±	10 days	Quenched in water
9.	4 specimens from 4 mines, Leadville.	600°C. ±	9 days	Quenched in water

Thus far none of the specimens heated has shown definite evidence of the chalcopyrite dissolving in the sphalerite. It seems certain that most sphalerite must form below 600 degrees Centigrade and therefore experiments at higher temperatures would be of less significance. The fact that a solid solution does not form at these temperatures should not be considered proof that the original intergrowth did not form by unmixing as these changes are not always reversible. The experiments do indicate, however, that thus far we can not depend on experimental evidence to prove that the intergrowths of sphalerite and chalcopyrite form by unmixing as suggested by Schneiderhöhn.

Read by title in the absence of the author.

REPLACEMENT ORIGIN OF THE ALBITE GRANITE NEAR SPARTA, OREGON[1]

BY JAMES GILLULY

(*Abstract*)

The albite granite near Sparta, in the foothills of the Wallowa Mountains of eastern Oregon, is thought to be a product of albitization and partial silicification of an earlier quartz diorite. These changes are attributed to late magmatic and post magmatic replacement of the almost completely solidified quartz diorite by solutions derived probably through filter pressing from lower horizons of the same mass. These solutions were guided at least in part and probably entirely by brecciated zones in the quartz diorite.

Mineralogical changes effected were: The replacement of the andesine and subordinate orthoclase of the quartz diorite by albite, the replacement of some of the common green hornblende by the soda amphibole, hastingsite, and the introduction of large quantities of dark-blue quartz. The habit of this quartz is decidedly different from that of normal granites in that the blue quartz occurs in irregular nests and veinlets penetrating the rock in many directions. Most of the dark minerals have been removed. Myrmekite and micrographic textures are common in the albite granites, though absent from the unaffected quartz diorite.

That the albitization and other changes of the albite granite have resulted from later reactions on the quartz diorite is shown by field relations, microscopic study and chemical analyses. The process is considered analagous to that of large-scale pegmatization.

The rocks are all of presumable Mesozoic age.

RELATIONSHIP OF CHLORIDE CONCENTRATION IN UNDERGROUND WATERS TO SUBSURFACE TEMPERATURE GRADIENTS[2]

BY F. B. PLUMMER AND E. C. SARGENT

(*Abstract*)

The results of analyses of underground waters and temperature measurements in wells collected throughout the extent of the Woodbine sand-sheet in Texas are presented. A normal rate of increase in salinity from the outcrop of the water sand down to the belt of connate waters is shown. A less than

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Released for publication by the American Petroleum Institute under whose auspices the investigation has been carried on as Research Project No. 25B.

normal rate of increase in the area occupied by the connate waters and a decidedly abnormally rapid rate of increase in the immediate vicinity of faults and salt domes is brought out. The lines of equal salinity do not follow the regional structural lines exactly but encircle each important local abnormal structure, whether it is a fault, salt dome, or anticline. The isotherms have the same direction as the regional structural contours. There are, however, abnormally high rates of increase in temperature with depth in the vicinity of faults and salt domes. The areas of abnormal subsurface temperatures correspond approximately to the areas of abnormally high salt concentration in the underground waters and are related to abnormal structure. The causes of these abnormal temperatures and salt concentration are briefly discussed and the relationship of abnormal temperatures and salt concentration to the spacing of oil pools is shown.

Presented by the senior author.

ADIRONDACK MAGMATIC STEM

BY A. F. BUDDINGTON

(*Abstract*)

The intrusive rocks of the Adirondacks vary from anorthosite and gabbro through various syenitic and granosyenitic types to granite. The series is assumed to be genetically related, and a study presented of certain specific possibilities of their origin by means of fractional crystallization. The formation of anorthosite by gravitative crystal sorting in a deep-seated chamber and subsequent filtration-differentiation of the plagioclase rich magma at the site of its emplacement higher up in the crust is discussed. The syenitic and granitic rocks are interpreted as residual magmas whose characters are the result of low fractionation. A comparison of the Adirondack series is made with other stems and it is concluded that the Adirondack rocks may be ascribed to a pyroxene (diopsidic) line of descent in the early and part of the intermediate stages of differentiation, and to a hornblende line of descent in the latter part of the intermediate and in the granitic stages. A characteristic feature of the differentiation is the relatively prolonged delay in the formation and separation of quartz. Differentiation is believed to have proceeded in much drier magmas than those of the more hornblendic Coast Range-Sierra Nevada series, and in slightly wetter magmas than the more completely pyroxenic Bergen-Jotun or Christiania stems.

CALCITE-BEARING DIABASE NEAR MORTON, WASHINGTON

BY G. E. GOODSPEED†

(*Abstract*)

Near the town of Morton, in Lewis County, sills of a calcite-bearing diabase intrude sediments which belong, presumably, to the Puget series. The rock from the central portions of the sills is of medium grained texture, and has a distinctly fresh appearance, yet contains a visible amount of calcite. The

† Introduced by Charles E. Weaver.

microscope shows that the carbonate for the most part is interstitial, but has to some extent replaced the pyroxene. It is associated with a chloritic mineral. The calcic plagioclases are relatively unaltered, as is the case with the pyroxene which has not been replaced by the carbonate. A chemical analysis of the rock shows 6.30 per cent of CO_2, 0.50 per cent H_2O-, and 0.72 per cent H_2O+. From the petrographic character and the chemical analysis it is believed that the usual assumption of hydrothermal alteration is not tenable in this case.

EVIDENCE ON THE GRAVITATIONAL ACCUMULATION OF OLIVINE DURING THE ADVANCE OF A BASALTIC FLOW

BY RICHARD E. FULLER [1]

(*Abstract*)

In southeastern Oregon, on the eastern scarp of Steens Mountain, a basaltic flow shows a basal concentration of olivine grains, which average over 1 millimeter in diameter. The flow is approximately 30 feet in thickness. The upper zone, which is free from olivine, has a thickness of approximately 10 feet, while the enriched zone is about twice that size.

Since the chilled base of the flow, with a relatively low concentration of olivine, presumably represents the initial composition of the basalt, the impoverishment of the lava forming the upper zone can account for only one-sixth of the concentration beneath it. The enrichment is therefore attributed to the settling of olivine during the advance of a very fluid flow. Due both to basal chilling and to the concentration of the coarse grains, the viscosity of the lower zone would have been increased, while the more mobile upper zone, from which the olivine was continuously sinking, would have continued to advance. The accumulation of the olivine phenocrysts might thus be somewhat analagous to the deposition of sediments in a river.

At the conclusion of this program the session was adjourned at approximately 5:30 o'clock.

MEETINGS OF MONDAY EVENING

PRESIDENTIAL ADDRESS BY R. A. F. PENROSE, JR.

The address of the retiring President, R. A. F. Penrose, Jr., entitled "Geology as an agent in human welfare," was delivered before a large audience made up of the combined societies and invited guests at the Royal York Hotel at 8 o'clock. This address is published elsewhere in this number of the Bulletin.

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[1] Introduced by Charles E. Weaver.

ANNUAL SMOKER

At the conclusion of the presidential address the members of the Geological Society of America and of the affiliated societies and their guests participated in the complimentary smoker given by the local members of the Society. There was a very large attendance and an excellent opportunity was given for renewal of acquaintances and for general social enjoyment. Special entertainment was provided in the form of music and dancing, which was greatly enjoyed and proved to be very restful after the long scientific sessions of the day.

SESSION OF TUESDAY MORNING, DECEMBER 30

The session was called to order at 10:10 o'clock by President Penrose, in Room 22, Mining Building, University of Toronto. The first portion of the session was taken up by additional matters of business, carried over from the previous day; and the rest of the session was devoted to scientific papers listed on the official program.

REPORT OF THE AUDITING COMMITTEE

To the Geological Society of America:

We, the auditors appointed by the Society at its meeting on December 29, have examined the vouchers and other documents in the hands of the Treasurer, have compared them with the report submitted by the Council, and find that the accounts are correct. The securities in the safe deposit vault in Baltimore will be checked by Mr. Singewald and a report submitted to the Secretary.

Respectfully submitted,

JOHN B. REESIDE, JR.
CHESTER R. LONGWELL.
December 29, 1930. JOSEPH T. SINGEWALD, JR.

This report was received and accepted, conditioned on receipt of an additional section of the report covering the securities.

REPORT ON SECURITIES OWNED BY THE GEOLOGICAL SOCIETY

The following list of securities was verified by Professor Singewald, as shown by the letter attached hereto:

Stocks:

10 shares of the capital stock of the Iowa Apartment House Company, Washington, D. C.

40 shares of the capital stock of the Ontario Apartment House Company, Washington, D. C.

Bonds:

2 Texas and Pacific Railway Company First Mortgage 5% bonds.
2 Fairmont and Clarksburg Traction Company First Mortgage 5% bonds.
2 Consolidation Coal Company First and Refunding Mortgage 40-year 5% Sinking Fund Gold bonds.
3 Chicago Railways Company First Mortgage 5% Gold bonds.
2 Southern Bell Telephone and Telegraph Company First Mortgage 5% bonds.
1 Commonwealth Edison Company First Mortgage Gold bond.
2 American Telephone and Telegraph Company 20-year Sinking Fund 5½% Gold Debenture bonds.
2 Baltimore and Ohio Railroad Company First Mortgage 5½ bonds.
2 Commonwealth Edison First Collateral Trust 5% bonds.
2 Central Railways of Baltimore First Mortgage 5% bonds.
2 Canadian Pacific Railway Company 4½% bonds.
3 Southern Pacific Railway Company 40-year 4½% bonds.
2 Shawinigan Water and Power Company First Mortgage A bonds.
2 Canadian National Railway 40-year 4½% bonds.
3 Consolidated Gas, Electric Light and Power Company, Baltimore, 4½% bonds.
2 Carolina Power and Light Company 5% bonds.
2 Province of Ontario 5% bonds.
2 City of Montreal 5% bonds.
2 Delaware and Hudson Company First and Refunding Mortgage 4% bonds.

Penrose Gift:

5 City of Philadelphia 4% loan of October 1, 1920.

To the Secretary:

As one of the auditors of the accounts of the Treasurer of the Geological Society of America, I have this day examined the securities belonging to the Society and find that they correspond with the list as published in the annual report of the Treasurer, 1930.

JOSEPH T. SINGEWALD, JR.

January 10, 1931.

TITLES AND ABSTRACTS OF PAPERS

TERTIARY RECORD OF SEQUOIA ON SAINT LAWRENCE ISLAND, ALASKA

BY RALPH W. CHANEY

(*Abstract*)

The recent discovery of foliage, cones and wood of *Sequoia langsdorfii* in beds of Tertiary age on Saint Lawrence Island confirms the theory of a land connection between North America and Asia during this period. Broad-leafed associates of the Sequoia are represented by only fragmentary specimens on

the slabs of shale; they include a large-leafed species of poplar, resembling *Populus richardsoni*, and what appear to be alder and sycamore. All of these genera are represented in the Tertiary floras of Manchuria and Siberia in Asia, and at numerous localities from Alaska to California and Colorado on the American side of the Pacific. Their occurrence on Saint Lawrence Island, at 63½ degrees north latitude, approximately 50 miles from the nearest shore of Asia and 100 miles from North America, gives critical evidence of the continuity of the redwood forest from North America to Asia during the Tertiary.

Read by title in the absence of the author.

GEOLOGY OF THE BAHAMAS

BY R. M. FIELD

(*Abstract*)

An international expedition to the Bahamas operated between January 1 and April 15, 1930. The general object of the expedition was to study the character of the Bahama "block," and the relation of its stability to the origin and history of the sediments which mantle its surface. This year's expedition was a cooperative undertaking sponsored by the Council of the International Summer School of Geology of Princeton University and supported by the following institutions:

1. The Rouse Ball Fund of Trinity College, Cambridge, and the Percy Sladen Trust of London; Mr. Maurice Black in charge of the geology of Andros Island.
2. Die Notgemeinschaft der Deutschen Wissenschaft, which partly financed Dr. Werner Bavendamm, in charge of bacteriology.
3. The American Museum of Natural History; Dr. Roy Miner in charge of marine zoology.
4. The Buffalo Society of Natural Sciences; Dr. Charles Fish in charge of oceanology.
5. The United States Geological Survey; Dr. William Bowie in charge of gravity measurements.
6. The Geological Survey of Great Britain; Mr. Ernest Dixon in charge of sedimentation.

At least two more years' work is planned in the British West Indies. The facts so far discovered do not permit too general a synthesis as to the geological history of the region, but are believed to be of sufficient interest to warrant the following statements:

1. The Bahama "block" is practically in isostatic equilibrium, but has been undergoing slight plus and minus movements.
2. The margins of the "block" show evidence of having been limited by a fracture system probably in pre-Pleistocene times.
3. The bulk of the calcium carbonate mud on the Bahama banks has been derived from the west coast of Andros Island.
4. Marine bacteria (in the sea water) are probably a negligible factor in the precipitation of calcium carbonate.

5. A large and interesting number of new bacteria have been discovered in the carbonate muds, the most important of which are the anaërobic and agar-agar liquifying bacteria. All bacteria are relatively much more abundant in the muds and fresh and brackish waters of Andros Island than in the marine waters covering the banks.

6. There is little or no evidence that an appreciable quantity of calcium carbonate mud is being precipitated from the marine waters covering the Bahama banks.

7. The carbonate muds which cover a large part of Andros Island contain *only* land and fresh or brackish water organisms.

8. There is no *direct* evidence that the carbonate muds in Andros Island or the muds covering the banks are of marine origin.

9. The Bahama region may throw some *new* light upon the origin and source of Paleozoic and post-Paleozoic limestones.

GEOLOGY OF SOUTHERN NICARAGUA

BY CARROLL H. WEGEMANN

(*Abstract*)

The area discussed lies between Lake Nicaragua and the Pacific. Upper Cretaceous shales and sandstones 5,000 feet in thickness are for the first time recognized in Nicaragua and can be correlated by foraminifera with the Mendez of the Tampico region in Mexico and the Taylor and Navarro of Texas. Such correlation infers interoceanic connection between the Atlantic and Pacific in Upper Cretaceous time. Of the Eocene, 8,000 feet of shale and sandstone is present and can be divided on its foraminifera into three divisions which cannot, however, be correlated with divisions of the Eocene in other regions. The Oligocene consists of 2,500 feet of shale and sandstone which can be correlated by foraminifera with the lower division of the Oligocene, in the Tampico region known as the Alazan. The upper division of the Oligocene of Mexico is apparently absent in Nicaragua. Miocene Coquina limestone about 100 feet in thickness overlies unconformably upturned beds of the Oligocene and appears to be equivalent to the Gatun of Panama.

There was continuous sedimentation from Cretaceous to Oligocene and the different periods can be distinguished only by their foraminifera. Volcanic activity continued through Cretaceous and Eocene but was not pronounced in lower Oligocene time. The major folding in the region occurred in Upper Oligocene and Lower Miocene time and was followed by peneplanation before the deposition of the Middle Miocene.

ZONE OF CAVITIES AND ZONE OF CONTINUITY

BY ROLLIN T. CHAMBERLIN

(*Abstract*)

In spite of clear statements to the contrary, the idea prevails that there is a zone of fracture extending down several miles and that below this is a zone of flow where the rock materials are in a plastic or semiplastic condition and

where fracture mechanics do not function. The results of this latter concept have been very insidious.

Old tombstones are found to have bent notably in the course of time. This warping has been accomplished by true rock flow. The zone of flow thus extends to the surface and even above the surface of the earth. On the other hand, earthquakes due to faulting appear to have originated at depths as great as 50 kilometers. Both solid rock flow by recrystallization and displacement of large aggregates by shearing are in operation from the surface of the earth down to very considerable depths. With this picture, distinct zones of fracture and flow in the surficial portions of the earth vanish completely.

Accordingly there is here suggested, instead, the zone of cavities and the zone of continuity. The presence of cavities introduces local differential stress and tends to facilitate deformation, especially by solid rock flow. In the zone of continuity below, rock fracture with distinct parting does not occur, but the closely related process of rock shearing does operate. The zones of fracture and flow were based on processes which overlap throughout the outer shell of the earth, and the term flow has proved misleading. The zones of cavities and continuity are based on structure and seem less likely to lead to faulty ideas.

SEISMIC MAPS OF THE MAJOR EARTHQUAKES, 1899–1923

BY CHESTER A. REEDS

(*Abstract*)

In 1923 the American Museum of Natural History, New York, published a seismic map of the world, which showed the distribution of the epicenters of major earthquakes for the twelve years, 1899-1910. Similar data for a 25-year period, 1899-1923, has now been assembled and plotted on a world map. During this period 1,783 earthquakes occurred, each of which was recorded at seismic stations distributed more than half-way around the world. The map shows that the epicenters of these quakes are confined for the most part to two great circles, one circum-Mediterranean, the other circum-Pacific. These apparently are the major zones along which the present great stresses and strains in the earth's crust are being adjusted.

At this point President Penrose relinquished the chair of presiding officer, and Past-President David White assumed that position.

CENTRAL AFRICAN VOLCANOES IN 1929

BY N. L. BOWEN

(*Abstract*)

The volcanoes in the vicinity of Lake Kivu were visited in 1929 by a party working under the joint auspices of the Geological Survey of Uganda and Carnegie Institution of Washington. The westernmost volcanoes of the group, Ninagongo and Namlagira, were in an active phase. Namlagira was ascended

and its activity viewed at close range. The crater is composite, with terraces and an inner lava pit. Lava fountains were playing in lava lakes on the ropy floor of the pit and lava was streaming over a cliff into a still deeper sink at the southern extremity of the crater.

THEORY OF APPALACHIAN EVOLUTION

BY DOUGLAS JOHNSON

(*Abstract*)

Interpretation of many features of Appalachian geomorphology is greatly simplified if we imagine the drainage to have been superposed from a coastal plain cover deposited on a very ancient peneplane of pre-Schooley (or pre-Kittatinny) age. The theory suggested for discussion calls for a former northwestward extension of the Atlantic Coastal Plain 125 to 200 miles beyond the present eroded inner margin of the deposits; it assumes that the surface upon which the extended coastal plain rested must have beveled the Appalachian folds at a level which now passes well above the highest erosion surfaces still partially preserved in the northern Appalachians; and it provisionally correlates this ancient surface, now completely destroyed in the Appalachian region, with the crystalline floor underlying the coastal plain beds. Some objections to the theory are presented, as well as facts which seem to favor its acceptance. It is concluded that the available evidence warrants us in giving the theory a place among other working hypotheses in our efforts to solve problems of Appalachian geomorphology.

Brief remarks were made by Miss Bascom and by Messrs. Arthur Keith, George H. Ashley and Frank A. Melton.

GEOPHYSICS, A NEW TOOL FOR THE GEOLOGIST

BY E. DE GOLYER

(*Abstract*)

The rocks which constitute the earth's crust have many physical qualities beyond those which may be determined commonly and easily by the geologist in the field or laboratory. Some of these characteristics are determinable by the physicist with great precision even for rocks lying hundreds or thousands of feet below the surface and serve as a means for identification of deeply buried rocks and in the determination of their position. Such use of precise physical measurements as an aid in the investigation of the constitution and structure of the earth's crust is termed geophysics.

Geophysics is not a new science, but its application on a broad scale to the more ordinary field problems of the geologist is of comparatively recent date—in fact, less than ten years old. During that period it has made enormous advances and is today one of the most rapidly developing methods at the disposition of geologists.

Numerous salt domes have been found as a result of gravity and seismic surveys. Anticlines and synclines have been indicated by gravity surveys. Buried granite hills and volcanic plugs have been located by magnetic surveys. Deposits of metallic ore have been located and outlined by electromagnetic surveys, and a technique for determining with a remarkable degree

of accuracy the position of deeply buried beds by the use of sound or seismic reflections has been developed.

The granite floor of the San Joaquin Valley in California has been traced to a depth of more than 25,000 feet. Depths to the Viola limestone in Oklahoma under a marked unconformity and more than 4,000 feet below the surface are being determined to within 25 to 50 feet as subsequently checked by drilling.

This new tool for the geologist, developed chiefly in economic geology, is of the greatest potential importance in the further advancement of the science of geology.

FUTURE OF PETROLEUM GEOLOGY

BY SIDNEY POWERS

(*Abstract*)

The petroleum industry is now in the same status as the mining industry was about fifteen or more years ago. Exploration work has been carried out so extensively in the United States that geologists have almost completed areal mapping and are engaged in subsurface studies—correlation of wells by means of microscopic examination of cuttings—and in interpretation of geophysical work. As opportunities for employment in the petroleum industry in purely scientific work become fewer, it is necessary for those who do not specialize in such branches as microscopic work or geophysics to seek employment in other branches of geology or in other phases of the petroleum industry, such as petroleum engineering. A knowledge of Spanish is desirable.

EARLY PALEOZOIC SEAS OF THE TEXAS REGION

BY E. H. SELLARDS

(*Abstract*)

Numerous writers have contributed to a knowledge of the location, character and faunal content of the Texas Paleozoic seas. Among these, special acknowledgment should be made to Schuchert, whose great publications, "Paleogeography of North America," 1910, and "Sites and Nature of North American Geosynclines," 1923, are fundamental to this problem. Ulrich and others have added greatly by their studies of faunas and their relationships.

In the earlier writings on this subject it was possible to utilize only surface exposures of formations plus their conjectured underground extension. However, as a result of the deep drilling of recent years new information has been obtained on the spread of the Paleozoic seas. By utilizing these records it is now possible to add to the information previously available, to check at many points the position of deeply buried formations and to more closely delimit the extent of the Paleozoic seas.

Among the new records obtained in recent years are the following which have been in part reported in the literature: (1) Additional support to the hypothesis advocated by numerous writers that a deep geosyncline existed in Texas at the inner margin of the land mass Llanoria connecting northeastward with the Ouachita geosyncline of Oklahoma and Arkansas and possibly,

although less surely, westward with the Marathon geosyncline; (2) the mid-Ordovician sea extended into, probably across, west central Texas having been found under the southern part of the Texas Permian basin. In addition, new data have accumulated by which to check previous mapping on the extent of the Upper Cambrian and Lower Ordovician seas. These seas occupied a broad depression inland from the land mass Llanoria. The facies of deposition during the early Paleozoic in the geosyncline immediately in front of Llanoria differs from that of the shallow continental seas which repeatedly spread widely across the foreland. The paper contains a summary of the records now available of the extent of these early Paleozoic seas in the Texas region.

At approximately 1:08 p. m., the session adjourned for luncheon.

Session of Tuesday Afternoon

The afternoon session was opened at 2:15 o'clock, in Room 22, Mining Building, with Vice-President Florence Bascom in the chair.

TITLES AND ABSTRACTS OF PAPERS

READVANCES OF THE WISCONSIN GLACIER IN MAINE

BY EDWARD H. PERKINS

(*Abstract*)

Work by Flint and others in southern New England has pointed to a stagnation of the Wisconsin ice-sheet during the period of dissipation. The great development of eskers has been taken to indicate the same thing in Maine.

Work on the glacial gravels of the State during the last field season has produced evidence that in some places at least the ice readvanced after a first retreat which was followed by a marine invasion. This evidence consists of folded and faulted clays overlaid by till, drumloid forms resting on stratified wash deposits and an esker over fossiliferous marine clays. The older beds are in all cases fresh and show no weathering, soil layers or other evidence which might indicate an early glacial epoch. For this reason it seems best to assign all the beds to the Wisconsin epoch and to believe that locally at least the ice was in motion during the period of dissipation.

Brief remarks were made by Messrs. Marland P. Billings and Irving B. Crosby.

KAMES, KAME TERRACES AND DELTA PLAINS OF CENTRAL MASSACHUSETTS

BY THOMAS C. BROWN

(*Abstract*)

Numerous deposits of sand, gravel and small boulders with occasional large boulders occur in and around the valleys of central Massachusetts. Some of these are similar in general form to the weathered remnants of former sand

plains that might have filled the valleys, and this explanation of their origin has been current in the past.

Widespread construction work along the State roads in this vicinity during recent years, and the many pits opened to supply concrete aggregate have caused many of these sand and gravel deposits to be opened up. As a result fresh sections of the interior structures have been exposed on a more extensive scale than ever before. These internal structures prove that these sand and gravel deposits could not have been formed as deltas in open lakes.

Several typical examples will be illustrated and described and a method of formation suggested.

ESKERS OF CENTRAL NEW YORK[1]

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

During an extended reconnaissance of the Susquehanna drainage area in south-central New York, the constant occurrence of eskers or esker fragments in all the valleys of this river system could not escape notice. The network of subglacial channels here developed seems likely to have been as extensive as that of the northern Adirondacks, similarly involving the question of ice-stagnation and equally worthy of close study, but the remains are older and therefore more fragmentary.

Brief remarks were made by Dr. John L. Rich.

GLACIATION IN NORTHWESTERN ILLINOIS[2]

BY RICHARD FOSTER FLINT

(*Abstract*)

Northwestern Illinois presents three contrasting regions: (1) An area free of drift (the "Driftless Area"), (2) an area once covered by an Illinoian ice-sheet, and (3) an area later covered by a Wisconsin ice-sheet. The boundary between (1) and (2) is purely gradational. That between (2) and (3) is sharply defined. The contrast between the two boundaries arises out of a contrast between the two former ice-sheets. Area (3) exhibits a typical sequence of glacial depositional land forms: ground moraine, ridged end-moraine, and outwash plain, clearly recording a protracted halt of the front of an actively moving ice-sheet. Area (2), however, consists of a preglacially-dissected upland of moderate relief, very thinly veneered with till and scattering glacial pebbles, without moraines and without outwash. Stratified deposits of lacustrine and fluviatile origin are present in the form of crude terraces, elongate ridges, and knolls, lying at several accordant levels. These forms are not erosion remnants, but constructional ice-contact features, built up in simultaneous groups over the entire area, in lakes and streams marginal to masses of stagnant ice resulting from the dissipation *in situ* of the (Illinoian) ice-sheet rendered motionless in this region. The stratified deposits are genetically similar to those characteristic of the last glaciation

[1] Presented by courtesy of the Cities Service Company.
[2] Published by permission of the Chief, Illinois State Geological Survey.

over the entire region east of the Great Lakes, but their ideal form has been somewhat modified by post-Illinoian weathering, erosion and loess deposition.

ERRATIC BOULDERS OF LARGE SIZE IN THE WEST TEXAS CARBONIFEROUS

BY PHILIP B. KING, CHARLES L. BAKER AND E. H. SELLARDS

(*Abstract*)

The features described in this note are found in the Marathon region of western Texas, an area very similar in structure and rock facies to the Ouachita Mountains of Oklahoma and Arkansas. During the last field season King, and later Baker and Sellards, made observations here on a remarkable boulder bed, which greatly resembles similar ones in the Caney shale of the Ouachita Mountains. The bed lies in the upper part of the Haymond formation from which fossil plants of possible Pottsville age have recently been collected. The boulders are set rather widely in a matrix of arkosic mud, and overlie thick beds of arkose and thinner-bedded sandstone and shales. They consist of the following materials:

(*a*) Well rounded cobbles of pre-Cambrian crystalline rocks, including granite, gneiss, schist, aplite, and pegmatite. These are particularly interesting in view of the fact that there are no existing pre-Cambrian outcrops within many miles of the area.

(*b*) Large angular blocks of Paleozoic rock, including upper Ordovician limestone, Devonian chert and novaculite, and quartzite and limestone from the two subjacent Carboniferous formations. These Paleozoic masses reach tremendous size. Blocks 5 or 15 feet across are common, but the largest, measured by Baker and Sellards, is 100 feet across. The position of some of the large limestone masses, particularly those that are bedded and dip with the formation, may reasonably raise the question as to the possibility of their being unusual lentils of limestone lying within the Haymond formation. This does not seem probable and in any case this explanation could not apply to the numerous associated boulders representing various older formations.

(*c*) Angular blocks of siliceous fault breccia.

The deposit indicates clearly the rise of high lands in west Texas in early Pennsylvanian time, probably to the south of the area of the boulders. Not only is the fault breccia indicative of diastrophism and uplift, but the great variety of rocks represented, ranging in age from pre-Cambrian to Carboniferous, shows the subaerial exposure of beds which should normally be buried beneath thousands of feet of younger strata. The transporting forces, by which the materials were carried to their present position, are less evident. It is not likely that they have been brought in by normal stream or current transportation, or that they are landslide deposits. Among various possible transporting processes are mud flowage, ice rafting, glaciation and solifluction.

Presented by Mr. King.

Brief remarks were made by Messrs. H. D. Miser and E. H. Sellards.

RECESSION OF LAST ICE-SHEET IN THE TORONTO-NIAGARA REGION

BY FRANK BURSLEY TAYLOR

(*Abstract*)

Describes recessional moraines and other glacial features formed during the final retreat of the Wisconsin ice-sheet over this region, including also an account of the abandoned shore lines and other lacustrine forms associated with that retreat. The bearing of the facts found in this and adjacent areas on the three steps or divisions of the Wisconsin recession in New York and New England are briefly stated.

DISTRIBUTION OF DRUMLINS AND ITS BEARING ON THEIR ORIGIN

BY FRANK BURSLEY TAYLOR

(*Abstract*)

The major facts of drumlin occurrence and distribution are reviewed and it is pointed out that drumlins occur typically in association with rather wide, deep basins or lowland areas, although many exceptions may be noted locally. Certain of our Great Lakes basins and the lowlands of Ireland, Scotland and Scandinavia seem to have furnished the most favorable conditions. It is found that the best individual types and the most perfectly developed areas show that the process of drumlin formation is characterized not by notably or extra vigorous movement on the part of the shaping ice-body, as has been held by some, but rather by a more or less dispersive and hence by a slowing or dying-out movement. Variations of size, shape, axial ratio, etcetera, under different environments strongly supports this view. In Ireland, the favoring condition in the local relief is not a deep basin like that of Lake Ontario around which drumlins are so well developed, but the reverse—a cluster of low mountain peaks from which a small or diminutive ice-sheet moved out over the adjacent plain with a spreading, dying movement and the production of the most remarkable drumlin area in the world.

These two papers were read by title in the absence of the author.

RECENT DEEP BORINGS IN THE RICHMOND BASIN, VIRGINIA

BY ARTHUR BEVAN

(*Abstract*)

The Richmond Basin is near the eastern edge of the Piedmont province southwest of Richmond. It is an elliptical area, about 8 miles wide and 30 miles long, of Triassic sediments surrounded by Precambrian gneiss and granite. Diabase dikes locally cut the sediments.

Coal was reported in 1701 and mining was done as early as 1750. Much mining was done at intervals during the 19th century. Some deep shafts and borings were made, but the details of these operations have not been recorded. Borings are now being made in the eastern part of the basin in a new search for coal and natural coke.

Two borings have reached the underlying granite at depths of 487 and 583 feet. A boring in progress is more than 2,000 feet deep, and it has not reached the base of the sediments. The sediments are mainly thick gray arkosic sandstones and conglomerates with interbedded gray, black, and red shales, and a few beds of coal. The beds are, as a rule, rather steeply tilted toward the middle of the basin.

BLOCK FAULT STRUCTURES NEAR TICONDEROGA, NEW YORK

BY A. C. SWINNERTON

(*Abstract*)

Two field seasons spent by the Harvard Summer School of Field Geology under the writer's direction in studying the faulted area near Ticonderoga, New York, have developed the facts (1) that the faults are commonly arcuate flaws curving out of the Adirondack massif, (2) that in the series of faults the down-thrown block is tilted backward, namely, downward toward the west. A survey of the literature supports the contention that these features are common to the structures in the Champlain and Mohawk valleys to the south and west, and for some distance northward in the Champlain valley near the mountain border.

The conclusions offered are largely negative. (1) The structures seem to be out of harmony with any hypothesis which attempts to associate them with the Appalachian-Green Mountain structures immediately to the east, either as related to the preparatory geosyncline or to the ultimate mountain forming movements. (2) The faults appear to be related to the Adirondacks, and seem to be a peculiar structural type, not uncommon in the massif, the full significance of which awaits further investigation.

Brief remarks were made by Messrs. Kirtley F. Mather and George H. Chadwick, with reply by the author.

WISCONSIN TILLS-PATTERN AS COSMICALLY INITIATED

BY CHARLES KEYES

(*Abstract*)

Recent disclosure of three successive Wisconsin tills, which together with the present Greenlandian, indicate a four-stage epoch of the Last great Glacial cycle; and the reduction to graphic form of the Stockwell recalculations on the eccentricity of Earth's orbit, as well as, also, of Pilgrim's more recent figures of the same, on a short-interval basis, brings out a remarkable agreement between the premises of astronomical hypothesis of climate extremes and the observed facts concerning the complexity and clustered relationships of Glacial till-sheets.

The Last, or Wisconsin, group of Glacial tills may be taken, therefore, as the pattern for the study of all continental glaciations. Heretofore all results of Glacial investigations have been empirical and merely qualitative, with not even guiding-star to direct future developments. Astronomical hypothesis is

quantitative in character, with property of forecast of events into the future as well as into the instant past. Fitting of this Glacial model so closely to the conditions imposed by latest astronomical hypothesis makes the latter the working scheme henceforward, or at least until something better is formulated.

When glacial phenomena may be predicted from astronomical data astronomical hypothesis must be of greatest service to earth students' prediction of coming events, the real test of scientific doctrine, the one thing which no other explanation of periodic glaciation yet makes with satisfaction.

Read by title.

ADDRESS OF THE RETIRING PRESIDENT OF THE PALEONTOLOGICAL SOCIETY

At 3:30 o'clock, the hour announced for the joint session with the Paleontological Society, the meeting was taken in charge by Vice-President W. H. Twenhofel, retiring President of the Paleontological Society, who presented his address, entitled "Environment in sedimentation and stratigraphy." This address is published elsewhere in this number of the Bulletin.

At the conclusion of the address the program was continued with the titles as listed.

TITLES AND ABSTRACTS OF PAPERS

LOWER CRETACEOUS GASTROPLITES CANADENSIS ZONE OF THE NORTHERN CANADIAN INTERIOR[1]

BY F. H. MC LEARN

(*Abstract*)

The known *Gastroplites canadensis* fauna includes ammonoids, pelecypods and starfish of about Lower Albian date. In the northeast, on lower Peace River, it is in the Upper Sandstone member of the Peace River formation and far to the west in the Peace River canyon, where Lower Cretaceous beds reappear on the west side of the broad, shallow trough, it is in the Fort Saint John shale just over the Gates member. It makes possible the dating of these beds and a correlation between the eastern and western Peace River sections, shows that the Saint John formation of the west extends stratigraphically down much lower than the Saint John of the east and that the Saint John is partly of Albian age. The upper part of the Saint John is probably early Upper Cretaceous, as the writer has noted, and Cenomanian or early Turonian. The *Gastroplites canadensis* seems to have been a northern sea which did not extend very far in the southeast, not to the area of the lower Athabaska River nor even to the town of Peace River for the beds of equivalent age there, that is, those of the Upper Grand Rapids Sandstone, etcetera, appear to be nonmarine. It extended much farther to the southwest, however, to the Peace River canyon, and flooded the area once the site of deposition

[1] Published with the permission of the Director, Geological Survey, Canada.

of nonmarine beds of about Lower Blairmore age, that is, the beds of the Gething member of the Bullhead Mountain formation. The somewhat earlier Clearwater sea of late Aptian or early Albian time extended much farther to the southeast, but it is not known whether it extended westward to the site of the Peace River canyon.

One of the problems of the Canadian Lower Cretaceous is the source of the sands of the Peace River and Grand Rapids formations. They do not appear to have come directly from the west and must be from the southwest or the east. In southwestern Alberta the nonmarine Upper Blairmore may approximately represent the horizon of the *Gastroplites* zone.

UPPER AND MIDDLE CAMBRIAN AND OLDER ROCKS OF EAST-CENTRAL ALASKA

BY J. B. MERTIE, JR.

(*Abstract*)

Upper Cambrian rocks were first identified and described along the international boundary between Alaska and Yukon Territory by D. D. Cairnes, of the Canadian Geological Survey, in 1911 and 1912. Subsequent work west of the international boundary, between Yukon and Nation rivers, by the writer in 1925 and 1930, has resulted in the discovery of Middle Cambrian rocks, and in the subdivision of the pre-Middle Cambrian rocks into a number of units.

The formations so far recognized are as follows:

Ordovician and Upper Cambrian...	A. Massive limestone.
Upper or Middle Cambrian.....	B. Slate and quartzite.
Middle Cambrian.....	C. Massive limestone.
Pre-Middle Cambrian	D. Limestone, dolomite and quartzite.
	E. Red beds. Limestone, dolomite, shale and conglomerate.
	F. Ellipsoidal lava. Greenstone.
	G. Limestone, dolomite, shale and quartzite.
	H. Red beds. Red and blue slate and dolomite
	I. Lava. Greenstone.
	J. Limestone, dolomite, slate and quartzite. Base of sequence not exposed.

Cambrian fossils have been found only in formations A and C. The total thickness of rocks is about 20,000 feet, of which about a third is comprised by formations A, B, and C. No structural unconformity has definitely been recognized at the base of the Middle Cambrian limestone, but the great thickness of underlying rocks suggests that formations D to J, inclusive, may represent an Algonkian sequence.

UPPER PALEOZOIC GLACIATIONS OF AUSTRALIA

BY T. W. EDGEWORTH DAVID AND C. A. SUSSMILCH

(*Abstract*)

In 1919 the authors, in describing the Kuttung series of the Hunter River district of New South Wales, drew attention to the existence in this series of glacial beds associated with a Rhacopteris flora, showing therefore that the Upper Paleozoic glaciation of Eastern Australia had its beginning in Carboniferous times.

In 1928 Professor Charles Schuchert presented his summary of Upper Paleozoic geology and came to the conclusion that all the Upper Paleozoic formations of Australia containing glacial beds were Middle Permian in age.

In the present paper the authors summarize the whole of the existing knowledge with regard to the Carboniferous and Permocarboniferous glaciation of Australia, including all new information gathered since their previous paper in 1919. The evidence shows conclusively that glacial beds occur throughout the Kuttung series associated with a Rhacopteris flora and therefore are of Middle Carboniferous age. A very careful correlation is made of the various occurrences of strata of Kamilaroi (Permocarboniferous) age throughout Australia, and as a result, the authors come to the conclusion that there is sufficient evidence to warrant placing the lower part of what has formerly been called the Lower Marine series into the Upper Carboniferous. It is shown that these particular beds contain quite a number of marine fossils of undoubted Carboniferous affinities associated with beds containing the Glossopteris flora. The remaining portion of the Kamilaroi system is retained in the Permian. It is shown that in eastern Australia there are five distinct glacial horizons ranging from the Kuttung of Middle Carboniferous age (Kulm) to the Upper Marine series of Middle Permian age. These five horizons are distributed through a thickness of nearly 15,000 feet of strata.

Read by title.

At this point the session adjourned at approximately 4:30 o'clock.

VISIT TO ROYAL ONTARIO MUSEUM

Arrangements were made for inspection of the Royal Ontario Museum at 4:30 o'clock, Tuesday afternoon, and tea was served by Mrs. D. A. Dunlap for all those in attendance at the meetings. These additional opportunities for social entertainment were much appreciated and well attended.

ANNUAL DINNER

Three hundred and fifty-nine Fellows and friends of the Society, including members of the affiliated societies and visitors, assembled in the Great Hall of Hart House, University of Toronto, for the annual dinner, one of the largest in the history of the Society. President Penrose, after making a few remarks and expressing the appreciation of the So-

ciety for the excellent arrangements made by the Local Committee, introduced Past-President and chairman of the local committee A. P. Coleman, who was to act as master of ceremonies. The following persons responded with short after-dinner speeches: Charles Camsell, for the Canadian Department of Mines; W. C. Mendenhall, for the United States Geological Survey; W. H. Twenhofel, for the Paleontological Society; H. E. Merwin, for the Mineralogical Society; Sydney H. Ball, for the Society of Economic Geologists; Sidney Powers, for the American Association of Petroleum Geologists; and Alfred C. Lane, President-elect of the Geological Society.

PRESENTATION OF THE PENROSE MEDAL OF THE GEOLOGICAL SOCIETY OF AMERICA TO FRANÇOIS ANTOINE ALFRED LACROIX

Charles P. Berkey, Chairman of the Committee on Award, in presenting the medal to M. Rochereau de le Sabliere, Consul of the French Government at Toronto, for transmittal to the recipient, François Antoine Alfred Lacroix, made the following remarks.

PRESENTATION ADDRESS OF THE PENROSE MEDAL OF THE GEOLOGICAL SOCIETY OF AMERICA, BY CHARLES P. BERKEY, CHAIRMAN OF THE COMMITTEE ON AWARD.

Mr. President, Fellows of the Geological Society of America, Ladies, and Gentlemen:

Some years ago a foundation was established for the perpetual support of a medal to be awarded for distinguished outstanding accomplishment resulting in marked advancement in the science of geology. Geologists of all nations and races were to be equally eligible. In this spirit the Penrose Medal of the Geological Society of America was established. To receive it is one of the greatest marks of distinction in the field of geology.

The object of the Committee on Award is to select the most outstanding geologist in the world. Its recommendations are brought before the Council of the Society, where final responsibility rests for naming the medalist.

In former years there have been two recipients of this medal. The first, in 1927, was the late Professor Thomas Chrowder Chamberlin, of Chicago, the greatest of our American philosophic geologists, the man who did more to extend geologic time and process into the dim past and link up modern geology with astronomy than any other man in our time. In 1928 the medal was given to Professor Jakob Johannes Sederholm,

of Finland, a field observer and interpreter, the greatest of all delvers into the obscure and fragmentary records of the pre-Cambrian.

This year the committee has named a man who in their opinion meets every requirement in still a different field. In this the Council of the Society has concurred, and he has been designated to receive this medal. At this time I am therefore privileged to name François Antoine Alfred Lacroix, of Paris, as the medalist of the Geological Society of America.

Lacroix is a product of France, born on her soil at Macon in 1863; educated in her schools, first in his native village and later trained for higher service at her famous educational institutions in Paris. At the Sorbonne he received the degree of Doctor of Science in 1889. He was prepared for investigation by her own scientific men, was nurtured and encouraged by her own institutions and government, devoting his best effort to the problems of his country, to the description of her geologic features and the unraveling of her geologic history. He has been honored by his own countrymen in the same manner and to the same degree and for the same reason as others have honored him in every part of the world.

Lacroix has had a remarkable career—one of the most continuous and varied and extended of any geologist of our time. In 1893 he was appointed professor of mineralogy at the Museum of Natural History, Paris. In 1896 he was made director of the Laboratory of Mineralogy at the School of Advanced Studies. Later he became a member of the French Academy of Sciences and has been for many years the Permanent Secretary of the Academy of Sciences of the Institute of France. He is a member of the Academy of Agriculture, a commander of the Legion of Honor, and an officer of public instruction.

He has made many scientific expeditions, some of which have been enormously productive in his hands, including such widely scattered regions as the United States, Canada, the West Indies, England, Germany, Italy, Madagascar, and the East Indies.

When we consider the scientific contributions of this justly famous man, a still more astonishing evidence of accomplishment becomes at once apparent.

No fewer than 338 titles are listed to his credit, some of them volumes of monographic proportions and constituting in themselves sufficient basis for lasting fame. But the range and continuity of them is still more impressive, for it appears that the first one was published in 1881, almost 50 years ago. This antedates the founding of this Society by seven years.

Since that time his activity has been so constant and he has been so prolific with his pen that he could have filled a long series of Bulletins himself. This will be the more evident when one recalls that in 49 years he has averaged nearly seven papers a year. For the first 23 years not a single year passed without a title to his credit, only a few at first but increasing rapidly with time.

At the end of five years he was writing 16 or 17 papers a year. Several years are dropped out entirely at the time of the World War, but leaving that aside there was only three blank years in 49. The year 1905 is blank, but the following year 36 titles were published. Each time a blank or a low year means that an expedition or an appointment on public service has absorbed his time, and, usually, a return to his work has been marked by redoubled effort. Some of these titles are known to all students of geologic science the world over, such as:

Les Enclaves des Roches Volcaniques, 1893.
Minéralogie de France et de ses Colonies, 1893-1913.
La Montagne Pelée et ses Éruptions, 1904.
Mineralogie de Madagascar, 1922-1923.
Le Granite des Pyrénées et ses Phénomènes de Contact, 1901.

François Antoine Alfred Lacroix is undoubtedly the most persistent student of minerals and rocks and the greatest interpretative petrographer in the world today. He is the most prolific and consistent contributor to the field of petro-mineralogy and petro-volcanology that has appeared in our time or any other. There have been other brilliant men in this field, Dolomieu, d'Hauy, Daubree, Dana, Fouque, Michel-Levy, Zirkel, Rosenbusch, and Iddings. But Lacroix combines many of the elements of excellence from all of them in his descriptive contributions. His own countrymen call him "the philosopher of minerals and rocks"; and this seems to be an appropriate characterization of his place in the field of science.

His minerals become the keys with which to unlock the hidden treasures of geologic history. To him minerals make the birth of rocks possible. He is preeminently the interpreter of minerals and in this capacity and from this angle is as much geologist as mineralogist, and, to a larger degree than is usually appreciated, is the chiefest champion of the modern petrology.

His minerals come from the melting pot of the gods, those enormous natural laboratories hidden in the depths of the earth. He has set himself the task of reading their experience, a difficult bit of history that helps

materially in gaining a better understanding of the ways of the earth and her life history. So he has delved into that enigma of the geologist, the batholith, its processes of differentiation, its products and its relations and its incidental effects on secondary formations. His books are a veritable treasury of minute and delicate observation. Some of them are libraries in themselves, such as La Mineralogie de le France et de ses Colonies, which is a great treatise on mineralogy.

In a very real way he belongs not alone to France but to the whole world. As a scientist and natural philosopher, in the old sense, as a reader of the records that outline the history of the earth in its most obscure phases, he belongs to the empire of the mind, which knows no national boundaries.

The friends of geology in America, and the Fellows of the Geological Society of America in particular, wish that it might have been possible for Professor Lacroix to be present at this time to receive the medal in person. He writes that it is not possible because of pressing responsibilities and engagements in his own land.

Two letters from him, however, should be read.

PARIS, *le 30 octobre, 1930.*

Mon cher professeur Berkey,

Je veux vous remercier de la nouvelle que vous voulez bien m'envoyer. Je suis très nonoré par la distinction que la Société Géologique d'Amérique veut bien me décerner. C'est pour moi une grande fierté d'avoir été distingué par elle et de recevoir cette médaille Penrose à laquelle j'attache un très grand prix.

Les géologues des États-Unis jouent un tel rôle dans le dévelopment de notre science, que leur appréciation est des plus précieuses.

Je vous prie donc de transmetter à vos collègues mes plus chaleureux remercîments. Je ne pouzrai pas malheureusement vous les porter moi-même. Le fin de l'année est pour moi une période de grand travail dans mon Académie et je ne puis jamais m'absenter à ce moment. Veuillez donc m'excuser de n'être pas au milieu de vous le 30 décembre. Si vous voulez bien me le permettre, je vous écrirai une lettre que je vous prierai de lire en mon nom au banquet.

Croyez, mon cher docteur Berkey, à l'expression de ma haute considération et de mes sentiments très devoués.

A. LACROIX.

PARIS, *de 14 décembre, 1930.*

Mon cher Collègue,

Je reçois votre lettre dont je vous remercie et, par ce même courrier, j'envoie au Consul de France à Toronto mon speech de remercîment. J'espère que par cette voie, plus directe que celle de New York, il arrivera à temps.

Je tiens à vous remercier encore une fois, vous et tous vos collègues, de la marque d'estîme que vous voulez bien me donner et à laquelle je suis très sensible. Je vous serai obligé de dire à M. le président Penrose combien je suis honoré d'être un des premiers titulaires de sa médaille.

Bien cordialement à vous,

A. LACROIX.

In the absence of the medalist himself we are fortunate in having the official representative of his country, the Republic of France, the French Consul, resident in Toronto, Monsieur Rochereau de le Sablière, who has graciously consented to receive the medal and transmit it with due formality to Professor Lacroix.

Monsieur Rochereau de le Sablière, I have the honor, therefore, of placing in your hands this, the Penrose Medal of the Geological Society of America, given as a mark of great distinction, evidenced by outstanding original contribution and achievement marking a decided advance in the science of geology.

RESPONSE BY CONSUL R. DE LE SABLIERE, FOR PROFESSOR LACROIX

Mesdames, Monsieur le Président, Messieurs les Professeurs et Membres de la Société Géologique d'Amérique:

J'ai l'honneur de parler au nom du Professeur François Antoine Alfred Lacroix, Directeur du Laboratoire Minéralogique du Musée d'Histoire Naturelle de Paris, et aussi Secrétaire Perpétuel de l'Académie des Sciences de France.

J'avais espéré recevoir, à temps, un mot de l'éminent Professeur; j'aurais eu le plus grand plaisur à vous le lire, et, surtout, vous auriez été plus intéressés de l'écouter, que d'entendre les quelques mots qu'on a si aimablement demandé à son humble remplaçant de prononcer; mais la lettre de Monsieur Lacroix, malheureusement, ne m'est pas encore parvenue.

Je remercie vivement la Société Géologique d'Amérique de la distinction dont elle vient d'honorer le professeur Lacroix. Je sais la haute

valeur qu'il convient d'attribuer à la Médaille Penrose. Non-seulement le Fondateur de cette distinction, l'éminent Professeur Penrose, qui nous fait l'honneur de présider cette imposante réunion, rehausse grandement par sa personnalité la valeur de cette si artistique et magnifique médaille, mais votre distingué et dévoué secrétaire, Professeur Charles Berkey, a bien voulu m'apprendre que seulement deux médailles Penrose avaient été décernées jusqu'à ce jour: l'une, au Professeur T. C. Chamberlin, anciennement de Chicago; l'autre, au Professeur J. J. Sederholm, d'Helsingfors; Celle du Professeur Lacroix étant la troisième.

Encore une fois, Messieurs, merci pour le grand honneur que vous venez de faire à mon distingué compatriote; mais je tiens aussi à remercier, tout spécialement, le Conseil de votre Société. C'est ce Conseil, éclairé par l'activité laborieuse et infatigable du Professeur Berkey, qui, parmi les innombrables et remarquables travaux des géologues du monde entier, a fixé son choix sur ceux du Professeur Lacroix, de France, et a présenté ce dernier à votre Société, comme "Lauréat" de la Médaille Penrose.

J'ai l'honneur de représenter la France, dans l'Ontario, depuis bientôt vingt-cinq ans, et je sais, Messieurs, à quel point ma Patrie est reconnaissante des hommages rendus et des distinctions décernées à ses élites, sourtout lorsqu'ils viennent d'un pays Ami.

Oserais-je aussi vous avouer que la France est fière de ses fils, si nombreux, qui, dans tous les temps, dans tous les domaines, dans toutes les activités de la vie, dans toutes les branches de la science, ont révélé leur Génie, ont brillé avec éclat par leur Individualité; cette caractéristique si Française, dont les conséquences, quand on y réfléchit, sont Innombrables, et expliquent tant de choses!

Merci encore, chaudement, de la part de Monsieur de Professeur Lacroix!

Et maintenant, Mesdames et Messieurs, puisque nous voilà presque (30 décembre) à l'aube de l'An Neuf, comme le nommaient nos Druides, permettez-moi, en terminant, de vous souhaiter à tous, une *bonne et heureuse année!*

LETTER FROM PROFESSOR LACROIX [1]

Messieurs,

C'est pour moi un grand regret de ne pouvoir répondre à votre si aimable et si cordiale invitation; je suis fort privé de ne pouvoir être au milieu de vous ce soir.

[1] This letter was intended for reading in connection with the presentation exercises but not received until January 2, 1931.

M. le Consul de France veut bien vous présenter de vive voix mes excuses et, en même temps mes remercîments pour l'honneur que vous me faites en m'attribuant cette belle médaille Penrose, témoignage de la haute estime de mes confrères américains.

De tous les honneurs que peut recevoir un homme de science, les plus enviables sont ceux attribués par ses pairs. C'est vous dire quel prix j'attache à celui que vous me conférez.

Et ceci évoque devant mes yeux de vieux souvenirs, ceux de mon premier grand voyage, effectué en 1888. J'étais alors jeune étudiant; j'ai fait aux États-Unis et au Canada une longue randonnée qui a eu une grande influence sur ma carrière, en me mettant en contact avec quelques-uns des plus illustres géologues et minéralogistes de votre pays, en me montrant la grandeur de leur oeuvre, aussi bien que l'intérêt scientifique de vos montagnes et de leurs gisements, la richesse de vos collections. Et par dessus tout, je songe aux amitiés que j'ai contractées alors de ce côté-ci de l'Atlantique et que j'ai conservées!

A ce moment, j'étais surtout attiré par les questions minéralogiques, le démon des volcans ne m'avait pas encore saisi de ses griffes puissantes qui ne lâchent jamais leur proie.

J'ai présentes devant mes yeux, comme si elles ne dataient pas de quarante-deux ans, mes visites à James et à Edward S. Dana, à Brush, le New-Haven; à James Hall, dans sa maison de campagne d'Albany; à Harrington, dans la McGill University; ma recontre avec Arnold Hague et Iddings dans leur camp du Yellowstone Park; mes excursions au Colorado, à Pikes Peak avec Hillebrand et Whitman Cross, et encore au gisement des tellurures de Boulder, de topaze dans les rhyolites de Nathrop; ma visite au major Powell à Washington; la splendeur des collections de minéraux de Genth, de Koenig, de Bement à Philadelphia; mes excursions aux gabbros de Baltimore, sous la conduite de George Williams et encore à ceux de la Cortland Series. Que sais-je encore?

La Société géologique d'Amérique n'existait pas alors, mais elle était bien près de naître. Sur le conseil de mon ami, George F. Kunz, j'allais à Cleveland, au meeting de l'American Science Association. Les deux frères Alexandre et Newton H. Winchell, m'y servirent de parrains, et j'ai conservé, comme souvenir, le petit ruban bleu, porteur d'un numero servant alors à étiqueter chaque congressiste et permettant de préciser son diagnostic, en cas de rencontre. J'ai assisté à la réunion de la Section E, à la suite de la quelle fut discutée et décidée la création de votre Société.

L'étudiant de 1888 ne se doutait pas alors qu'il serait un jour membre honoraire et lauréat de cette nouvellement-née, devenue rapidement puis-

sante, et qui a déjà derrière elle un si brillant passé, en réunissant tous les géologues d'un grand pays dont l'influence est considérable dans le développement et les progrès de toutes les questions géologiques.

Vous voyez, Messieurs, que ma reconnaissance pour vous est grande et qu'elle a des racines profondes et lointaines. J'ai donc de bonnes raisons pour regretter de n'être pas avec vous ce soir pour vous le dire moi-même.

A. LACROIX.

SESSION OF WEDNESDAY MORNING, DECEMBER 31

The meeting was called to order by President Penrose at 10 o'clock, in Room 22, Mining Building, University of Toronto, and proceeded immediately to the reading of scientific papers.

TITLES AND ABSTRACTS OF PAPERS

REVERSED CYCLES[1]

BY FREEMAN WARD

The cross profile of a stream valley showing a valley within a valley is commonly considered as evidence of two cycles of stream erosion. A diagram

FIGURE 1.—*Standard two-cycle cross Profile*
From Pirsson and Schuchert "Textbook of Geology," Part I, figure 292 B.

from one of the standard textbooks is reproduced in figure 1. This indicates an upper, mature valley made in the first cycle; a lower, young valley made in the second cycle inaugurated by uplift.

[1] Manuscript received by the Secretary of the Society January 6, 1931.

It is believed that this same type of valley profile can result from a set of circumstances different from the sequence just mentioned. The facts on which this belief is based were secured while doing field work for the Geological Survey of Pennsylvania, and are as follows:

An observed cross profile consists of the following elements: A cliff at the base of a mature valley wall, a bordering rock platform, a trench of undetermined depth in the central part of the valley. The trench is nearly filled with

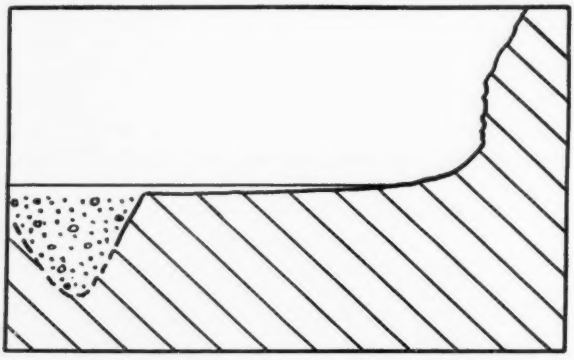

FIGURE 2.—*Profile of observed Conditions*

sands and gravel. These relations are shown in figure 2. At high water the platform is completely covered by the river, at very low water (such as has been the case during the dry season of 1930) the entire platform is exposed.

Lateral planation, during the migration of a meander, is obviously responsible for the cutting of the platform and is still in progress. Furthermore, the level at which this lateral planation was inaugurated was determined by the height of the fill in a previously cut young valley. If rejuvenation should occur the fill would all be removed and the river would again flow at the bottom of the youthful trench. The sequence of events, shown diagrammatically in figure 3, is as follows:

The end member *d* of the series has the standard cross profile of valley-within-valley like that in figure 1. But the age relations are the reverse of the standard, for the lower narrower valley was made *first* and the wider upper one *later*.

Three instances, such as described, have been seen in Pennsylvania; one was in the glaciated, two were in the nonglaciated part of the State. No doubt other localities will be found to have similar conditions, indicating some common diastrophic cause back of all of them. The occurrences suggest further that the valley-within-valley profiles seen in other parts of the country may, in some cases, need to be re-interpreted. The diastrophism required is less simple than in the standard cases; the filling may be the result of overloading without diminution of grade, such as occurs because of glaciation, but that

the filling should remain after the withdrawal of the ice means that the gradient has been lessened by downward movement. To complete the situation, uplift (after platform cutting) must occur to rejuvenate the stream.

A by-product of this study is the profile of equilibrium produced during lateral planation in uniform material. This is shown in figure 4. It will be seen that the rock platform is flat only in its outer part. The side toward the valley wall is a gradually steepening curve. During the normal stage of the

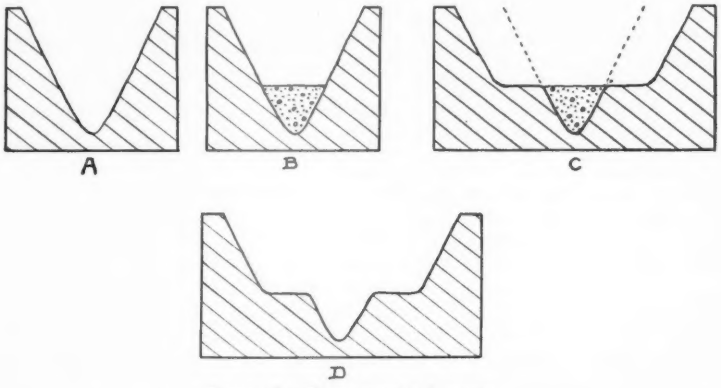

FIGURE 3.—*Diagrammatic Sequence*

(*a*) Making a young valley. (*b*) Partial filling of valley. (*c*) Lateral planation at level of fill, which is the present condition. (*d*) Rejuvenation and removal of fill.

river only the lower part is being eroded, the upper part is attacked only during flood stages. The lower part is eroded as long as there is any erosion both during normal and flood stages. The shoreward side never makes an angle with the cliff nor is there undercutting as in the case of a wave cut terrace.

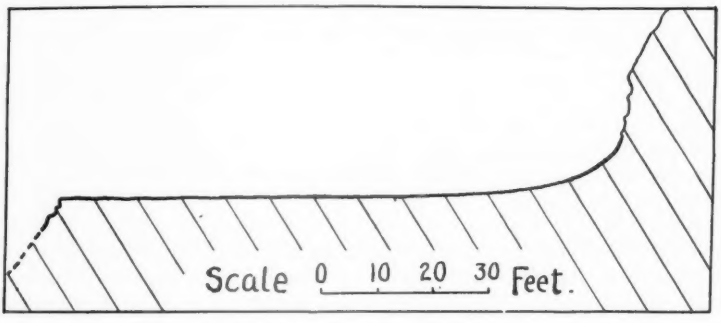

FIGURE 4.—*Profile of Equilibrium*

OUR YOUTHFUL SCENERY

BY GEORGE H. ASHLEY

(*Abstract*)

My thesis, presented not as proven but as questionably true, is that little, if any, of the face of the earth as known today antedates Miocene time, and that nearly or quite all of the details are post-Tertiary in age.

First, are noted the obvious and well-recognized changes produced by or since the Wisconsin ice advance.

Second, are studied the less obvious and commonly unrecognized changes of earlier Pleistocene time.

Finally, a rapid survey is made of the evidences that post-Oligocene movements, eruptions and erosions or sedimentations have probably transformed most other parts of the habital globe.

GEOGRAPHY OF NORTH AMERICAN GEOLOGY

BY CHARLES N. GOULD

(*Abstract*)

Data secured from 131 questionnaires sent to heads of departments of geology at the leading colleges and universities in the United States and Canada indicate that, at the present time, the subject of geology is receiving more attention in certain States in the Southwest, especially Texas and Oklahoma, than in any other part of North America.

Tables are presented indicating that the Southwest now leads other parts of the country in general geologic activity, in the number of working geologists, in the enrollment in courses of geology in various schools, in number of graduates, in number of active geological societies, and in number of field conferences held and number of miles traveled.

Brief remarks were made by Messrs. Douglas Johnson, Harry N. Eaton, and Charles P. Berkey.

GEOLOGY OF THE GASPÉ PENINSULA

BY W. A. PARKS

(*Abstract*)

The work of Sir William Logan made the Gaspé Peninsula a classic locality in Canadian geology. For many years after his time, little was done until a reexamination of the coast section was made by the late Dr. Clarke of Albany. Recently, however, the Geological Survey of Canada, and still later, the newly organized Bureau of Mines of Quebec have again directed attention to the area and several expeditions have added to our knowledge of the peninsula. The character of the folding in the sandstones is better understood, the subdivisions of the Silurian have been worked out, the large part played by

Devonian and post-Devonian vulcanism has been established, and the westward extension of Ordovician strata recognized. The paper is an attempt to assemble the results of recent investigations.

ADDITIONAL DATA ON THE GEOLOGY OF THE MINGAN ISLANDS

BY W. H. TWENHOFEL

(*Abstract*)

The Mingan Islands, Quebec, section consists of the Ordovician Romaine and Mingan formations and the Pleistocene. The Romaine formation lies nonconformably on the rocks of the Precambrian complex and in turn is overlain nonconformably by the Mingan formation, the angle of contact in the former case being very high and in the latter not exceeding 3 degrees. The Romaine and Mingan formations are not confined to the islands but make the shore in several places on the mainland, and on their eastern limit they form high hills extending into the interior for several miles. These hills are locally dignified by the name of mountains, as Mount Sainte Genivieve on the east side of Pillage Bay. The Ordovician rocks are briefly described and their geologic structures noted. New facts indicate their regional dip is probably much lower than has generally been assumed and this fact greatly decreases the thickness of strata concealed in the channel between the Mingan Islands and the Anticosti. The occurrence of mud cracks in the lower strata of the Mingan formation shows the shallowness of the water of deposition of this portion. Fossils are generally scarce in both the Ordovician formations, and are very poorly preserved in the Romaine formation. This statement for the Romaine formation does not apply to algal bodies of the Cryptozoon type as these are locally abundant and, in some cases, constitute entire beds. Fossils are more numerous in the Mingan formation, but with the exception of two horizons, they are never common. The main problem is concerned with the Glacial and post-Glacial conditions. Pre-Glacial plants have been found on many of the islands and the suggestion has been made that these survived the Ice Age where they now occur. As a basis for understanding the conditions during the Ice Age, the pre-Glacial physiography is described. The evidence on the Mingan Islands and the mountains of the mainland indicate that this entire region was buried beneath thick sheets of ice. This evidence shows the total removal of everything in the mountains to solid rock and the transportation of the material removed to some place south of the Mingan Islands. Furrows were cut in the hard rocks of the Mingan Islands to maximum depth of 3 feet and width of 20 feet. The Ice Age was followed by submergence, the facts indicating that the Islands were completely covered with the possible exception of high points on Eskimo and Large islands. The limestone hills of the mainland may not have been completely submerged. The conclusion is reached that the pre-Glacial plants must have reached the Mingan Islands in post-Glacial time, the migration possibly occurring at a time when the region of the Gulf of Saint Lawrence was free from the sea.

At this point President Penrose relinquished the chair of presiding officer to Past President Heinrich Ries.

BURIED PRECAMBRIAN OF WISCONSIN

BY F. T. THWAITES

(*Abstract*)

The configuration of the surface of the Precambrian rocks of Wisconsin which are buried by Paleozoic sediments is shown by a contour map. Records of wells which strike Precambrian rock from which samples have been examined by geologists are tabulated. This data shows that most of the buried Precambrian is igneous rock. Concealed Huronian rocks occur in several localities. It is suggested that two synclinal basins similar to the partially exposed Baraboo Range occur under heavy cover in eastern Wisconsin. Available information demonstrates that the surface of the buried Precambrian has more relief than had been supposed and that this relief affects the structure of the overlying sediments. Faulting and local folding in the Paleozoic rocks are thought to have been caused by renewed movement on Precambrian displacements. Level places on the Precambrian surface are best developed on massive or homogeneous rocks. Such are not very abundant. The kaolinitic clays seen on the surface of the Precambrian in exposures may have been mainly formed by weathering under existing conditions, but weathered rock of different character has been found in deep wells far from the border of the young rocks. Iron ore is the only proved economic resource of the concealed Precambrian, for reports of native copper have not been confirmed.

Brief remarks were made by Messrs. A. C. Lawson and Sidney Powers, with reply by the author.

TERTIARY DEPOSITS OF WESTERN KENTUCKY

BY JOSEPH K. ROBERTS

(*Abstract*)

The Tertiary deposits of western Kentucky are exposed at many points in what is known as the "Jackson Purchase Region" between the Tennessee and Mississippi rivers in the counties of Calloway, Marshall, McCracken, Graves, Fulton, Hickman, Carlisle and Ballard. The deposits lie unconformably upon the Upper Cretaceous sediments. The formations recognized comprise the lower and upper Eocene in part, and certain problematical deposits known as the "Lafayette," which are most likely Plio-Pleistocene in age.

The lower Eocene is represented by the Porters Creek clay, the only member of the Midway group, the Clayton wedging out in Tennessee. The Wilcox group is represented by the Holly Springs and the Grenada, the latter being very difficult to recognize, the Akerman or lower Wilcox not recognized. The Claiborne or middle Eocene is not present either in Kentucky or in Tennessee. Upon the Wilcox rests the sediments of Jackson age, which are found exposed along the bluffs of the Mississippi River from the town of Hickman in Fulton County northward at several points to Carlisle County. The Plio-Pleistocene

deposits of gravel and sand occur as a blanket over most of the Jackson Purchase Region.

The Porters Creek clay in a few places shows a development of a sandstone, and several sand dikes occur in it. It is the only marine formation of the entire Tertiary series. The Holly Springs consists of sand and interbedded clays, the latter showing quite a number of fossil floras in several localities. This clay is mined on a fairly large scale and put on the market as ball, sagger, and wad clays. The Grenada consists of sand and impure clays with only a few traces of fossil floras. The Jackson beds yield a few fossil leaves, and these consist of fine sands, and clays, some of the latter being indurated to a considerable degree. The Jackson is not exposed except along the bluffs but is covered by the gravels and sand of Plio-Pleistocene and by the loess and loam deposits. The deposits are quite similar to their equivalent to the south in Tennessee and other portions of the great embayment region.

Brief remarks were made by Messrs. U. S. Grant and Heinrich Ries.

TERTIARY MAGMATIC SEQUENCES OF THE FRONT RANGE, COLORADO

BY T. S. LOVERING

(*Abstract*)

The Tertiary igneous history of the Front Range interpreted from detailed work at many places indicates three types of magmatic differentiation. The first type, starting with an initially dioritic magma, resulted in basic and ultrabasic rocks. The second type, starting with a dioritic magma, gave rise successively to monzonite, quartz monzonite, granite and alaskite. The third type, starting with the quartz monzonite differentiate, resulted in alkalic rocks such as bostonites, alkalic syenites and alkalic trachytes. In the second type the magma became progressively more hydrous, and in the third type it became progressively drier.

Read by title in the absence of the author.

STRATIGRAPHY AND STRUCTURE OF THE UPPER MISSISSIPPI VALLEY

BY ARTHUR C. TROWBRIDGE AND GORDON I. ATWATER

(*Abstract*)

A recent review of the literature chiefly by the junior author and additional field work by the senior author during the last two summers in the making of surveys for damsites in the upper Mississippi Valley have yielded new information and led to new opinions, the more important of which are as follows:

The beds and the fossils of the Eau Claire formation of Wisconsin are included within the Dresbach formation of Minnesota. The Mazomanie sandstone in Wisconsin is equivalent to the Franconia sandstone on the Saint Croix and Mississippi rivers. The Norwalk sandstone is the practical equivalent of the Jordan sandstone at its type locality. The Mendota dolomite and

Madison sandstone are believed to be the equivalents of the Saint Lawrence dolomite and Jordan sandstone. There is an unconformity between the Oneota and Jordan formations on the Saint Croix and Minnesota rivers but only local unconformities on Mississippi River. The beds exposed at Shakopee, Minnesota, are probably Oneota rather than Shakopee.

An anticlinal axis crosses Mississippi River at Dresbach, Minnesota, in which given beds are 700 feet higher than at Saint Paul and 900 feet higher than at Dubuque. Faults at Hastings, Minnesota, have throws of 67 feet or more, at Red Wing, Minnesota, of 90-100 feet, between Stillwater, Minnesota, and Hudson, Wisconsin, of 300 or 400 feet. Willow River in Wisconsin flows from Oneota dolomite to a bed 100 feet or more below the top of the Dresbach in falling 24 feet vertically in a horizontal distance of 1½ miles.

Brief remarks were made by Messrs. E. O. Ulrich, Charles E. Resser, George H. Chadwick and F. T. Thwaites, with reply by the author.

ORDOVICIAN SECTIONS OF GREAT BRITAIN AND AMERICAN EQUIVALENTS

BY RICHARD M. FIELD

(*Abstract*)

Between 1922 and 1929 the writer has been particularly interested in the study of the type Ordovician sections of Great Britain, and has attempted to determine whether or not the British Postcambrian and pre-Silurian formations contained recognizable equivalents of the Ozarkian, Canadian or American Ordovician. As a result of the writer's preliminary visit to the British sections in 1922, Dr. Ulrich, in company with the writer, studied the Welsh and English sections under the leadership of Prof. O. T. Jones in 1927. In 1928 Professor Jones visited the United States as one of the foreign guests of the International Summer School of Geology and Natural Resources and, in company with Dr. E. O. Ulrich, Dr. Charles Butts and the writer, studied the Middle Ordovician of eastern North America from central Pennsylvania to Tennessee. In 1929 the Summer School arranged for a field conference on the British sections, which was led by Professor Jones, and in which Dr. Ulrich and the writer took part. The results of the investigation to date show the following:

1. There is no undoubted Ozarkian in England, Wales or Scotland.

2. The Middle and Upper Canadian is represented in the Durness limestone of the northwest Highlands of Scotland.

3. The Stinchar Valley section near Girvan contains equivalents of the typical Chazy of the southern Appalachians.

4. None of the "shelly" zones in the Welsh type sections of the Ordovician correlate closely with zones or formations in the Appalachian Valley, with the possible exception of a portion of the Upper Bala or Caradoc which appears to correlate most closely with the Salona, or Lower Trenton of central Pennsylvania.

5. The few close correlations which can be made between the Postcambrian and pre-Silurian formations of Great Britain and the Appalachian Valley do not occur in the type sections of Wales.

6. The problem of facies and faunal provinces is fully as important in Great Britain as it is in the eastern United States.

Brief remarks were made by Dr. Charles E. Resser.

METEORITES (SIDERITES OR AEROLITES) IN THEIR RELATION TO LIFE

BY GEORGE F. KUNZ

(*Abstract*)

After examining many meteorites in the collections at Mexico City, New York, Boston, Washington, London, Paris, Berlin, Munich, Budapest and Petrograd, I have noted the apparent absence of oxygen or of water, which latter would mean rusting and eating away of the material. Only minute masses of iron are found on the earth's surface because of such destruction, but this element is abundant in meteorites. Evidently very different conditions have prevailed from those on the earth.

The common presence of nickel, to the amount of approximately 7 per cent, associated with iron, is an interesting item but may be more difficult to interpret.

It is possible that these objects come from inter-stellar space; or it may be that they enter our atmosphere from various sources and that life may exist on some of the planets that have not thrown off meteoric masses of any kind.

None of the collections that I have examined has shown the slighest trace of any form of life whatsoever, indicating that life did not exist on the spheres from which they came.

GEOLOGICAL MARKING IN THE NATIONAL, STATE AND CIVIC PARKS OF THE UNITED STATES AND CANADA

BY GEORGE F. KUNZ

(*Abstract*)

Visitors to the national parks number several hundred thousand every year, and the number of visitors to the State parks reach several millions. Many millions also visit the municipal parks during this period of time.

It is proposed that a committee of the Geological Society of America be formed to arrange with the appropriate authorities for geological labels and markings. Such markings would be of incalculable value to these many visitors.

DIAMONDS IN NORTH AMERICA

BY GEORGE FREDERICK KUNZ

(*Abstract*)

In my preparation of the mineral resources of the United States from 1882 to 1905 and later in charge of the precious stone reports in Mineral Industry from 1905 to 1929, the subject of the occurrence of diamonds in North America was always a matter of great interest. In a careful report of mine, in which

all the occurrences of diamonds of North America were mapped, there were thirty-three localities in which diamonds were found, either in gravels or in accidental findings. There was in 1905, however, one locality of Murfressboro, Pike County, Arkansas, in which diamonds were found in peridotite rock. This was the first occurrence of diamond in place on the entire North American continent, either north or south. Of special interest to those attending the present meeting was the occurrence of an occasional crystal of diamond found in placer mining for gold near the Ohio River, in Brown County, Indiana. Some more than thirty diamonds were found here, although many more may have been lost. The panning for gold may be of interest in that both the diamond and the gold were undoubtedly of Canadian origin.

It occurred to me that to definitely trace the diamonds it might be possible to do this by examining the pebbles that were found in the mining. About fifty specimens of these pebbles that accompanied the gold and diamond findings were sent to the Ottawa meeting of the Geological Society of America twenty years ago. To my delight more than twenty of these various rock occurrences were identified by the United States and Canadian geologists who attended this meeting. The specimens are preserved and all are in my possession at the American Museum of Natural History. This proved conclusively that the rocks, the gold and the diamond had come from Canada and that the latter two have consciously or unconsciously been given to the United States by Canada in the Glacial period. Over 3,000 diamonds from ¼ to 40 carats were found, the latter of fine quality but very flat.

In 1893 the first of the diamonds, 12 carats in weight, was found in Eagle, Wisconsin. The finding of this was a little dubious but Dr. Hobbs on examination verified that the stone had really come from the well it was said to have been found in, and Dr. Hobbs' study of the condition there suggested that they probably had their origin at the James Bay district in Labrador, although the material found in Indiana was principally found in localities in lower Canada. The red and white jasper conglomerate came from Thessalon, on the north shore of Lake Huron.

About ten years ago, a Canada jeweler brought to me a rough broken diamond, scarcely more than about 33 carats, 6.5 grams, of little value as a gem but unusually interesting. It was found in the digging of a railroad cut between Ottawa and Toronto. The jeweler secured it by purchase from the finder. By a fatality no record was kept of the find and the jeweler died some years ago. The stone still exists.

It is interesting to note that the diamond crystals in Indiana and southern Indiana came from the north shore of Lake Superior and the diamonds found in lower Canada probably came from the James River lobe of the ice-sheet.

Lord Gray attended a reception at the American Museum of Natural History and when shown the diamonds, said, "Why not return these to Canada. You know that I returned the portrait of Benjamin Franklin to the descendants of the owner of the painting from whose house it was taken in 1776. Why not return these diamonds?"

At approximately 1:05 p. m., the session adjourned for luncheon.

Sessions of Wednesday Afternoon

In addition to the regular afternoon session, presided over by Vice-President Nelson H. Darton, a special section had been arranged in which introduced papers by nonmembers of the Society were presented. This sectional meeting was presided over by President-elect Alfred C. Lane.

SECTIONAL MEETING OF WEDNESDAY AFTERNOON

The sectional meeting for introduced papers by nonmembers was opened at 2 o'clock, in Room 26, Mining Building, with President-elect Alfred C. Lane in the chair.

TITLES AND ABSTRACTS OF PAPERS

METHODS FOR SAMPLING INCOHERENT SANDS AND DETERMINING THEIR POROSITY

BY H. J. FRASER [1]

(*Abstract*)

Two methods are described for obtaining samples of sand and similar incoherent materials in the field without disturbing the arrangement of the grains or changing the porosity. The first method is applicable to wet or damp sands and similar materials. It takes advantage of the coherency of fine-grained material when wet and consists in dipping the sample in paraffine and thus coating it with a rigid shell which preserves the arrangement of the material and permits transportation of the sample. In the second method, which is more satisfactory for coarser-grained and dry materials, the sands are impregnated by paraffine or similar substances and thus given an artificial coherency which permits them to be handled and transported as desired. Precise methods are given for determining the porosity and similar related properties of samples thus collected. The values so derived may be taken as reasonably accurate determinations of the properties of the material *in situ*.

ORDOVICIAN OF NOTRE DAME BAY, NEWFOUNDLAND

BY ALFRED K. SNELGROVE [2]

(*Abstract*)

The investigations of Princeton Geological Expeditions to Notre Dame Bay, northeast coast of Newfoundland, and the work of the writer in the Betts Cove-Tilt Cove area of the same bay, permit a tentative summary of the Ordovician stratigraphy and history of that region.

In the Betts Cove-Tilt Cove area, the Ordovician sequence begins with the nearly isoclinally folded Snooks Arm series, made up chiefly of three thick

[1] Introduced by L. C. Graton.
[2] Introduced by Edward Sampson.

units of andesitic pillow lava, two of which may be repetitions of the same flows. Interbedded with the pillow lavas at various horizons are andesitic pyroclastics and slates, etcetera. The graphitic slates of this series, containing *Loganograptus logani* and *Didymograptus gracilis* are pronounced by Ruedemann to be equivalent to the second and third Deep Kill zones of America and the Middle Arenig of Great Britain.

Overlying the Snooks Arm series with apparent conformity, outside the zone of isoclinal folding, are the less deformed Goss Pond volcanics, consisting of rhyolitic pyroclastics and some andesite and rhyolite lavas.

The youngest volcanic rocks are the Red Cliff volcanics, made up of rhyolite and dacite flows with minor amounts of andesite and rhyolitic pyroclastics.

All of these rocks are assigned to the Ordovician because of the graptolites in the Snooks Arm series and the apparent conformity of the two overlying formations. They are invaded and deformed by Devonian? (Acadian?) igneous rocks.

In Notre Dame Bay generally, no further evidence of late Canadian (Middle Arenig or second and third Deep Kill zones) volcanic activity is known. The wide-spread Normanskill (Glenkill, Middle Ordovician) black shales of Notre Dame Bay are locally associated with pillow lavas. The restricted Snake Hill slates in the interior of the island are obscurely related to another Ordovician? pillow lava eruption.

In Ordovician time much of Notre Dame Bay and northern central Newfoundland was evidently a continuation of the Levis trough of the Appalachian geosyncline, through which the typical Normanskill pelagic fauna is supposed to have migrated southwestward from the North Atlantic.

The Ordovician of Notre Dame Bay is contrasted with that of other Newfoundland and northern Appalachian sections and is shown to be similar to certain Scottish sections.

Brief remarks were made by Prof. Edward Sampson.

ORDOVICIAN BENTONITE IN MISSOURI

BY VICTOR T. ALLEN [1]

(*Abstract*)

The altered tuff layer occurring in the Decorah formation of Minnesota 18 inches above the top of the Platteville limestone has been identified in Iowa and Wisconsin in Kay's Spechts Ferry member, 12 to 18 inches above the top of the Platteville limestone. In Missouri 7 to 10 inches of bentonite are present at the base of green shales alternating with limestone that overlie the Plattin limestone. An excellent exposure is near Koch Valley in the Kimmswick Quadrangle, 26 miles south of Saint Louis on highway 61. Irregular solution surfaces at the top of the Decorah indicate erosion before the deposition of the overlying Kimmswick limestone and locally all the Decorah may be lacking.

This altered volcanic ash was probably formed by the same eruption described by Nelson in the East. In Missouri it is valuable in marking the

[1] Introduced by Chester K. Wentworth.

contact with the underlying Plattin and it supports Weller's correlation of these beds with the Decorah formation of Iowa. The petrography of the bentonite is discussed.

Brief remarks were made by Prof. U. S. Grant.

HOUNSFIELD METABENTONITE

BY G. MARSHALL KAY [1]

(*Abstract*)

In northwestern New York the Black River group consists of the Lowville and Chaumont formations. Near Dexter, Hounsfield metabentonite separates the Leray and Watertown members of the Chaumont; at Middleville the metabentonite lies beneath Trenton limestones, Watertown being absent. Similarly thin metabentonite occurs in Glenburnie shale near Kingston, Ontario; and in Coboconk limestone near Orillia. In the upper Mississippi Valley a 2-inch metabentonite persists a foot from the base of the Spechts Ferry shale. Much thicker metabentonite beds in Kentucky, Tennessee and Alabama occur in beds that have been correlated with the upper Black River and basal Trenton.

Each of these metabentonites seems to be the Hounsfield. The including beds in the north had been correlated definitely prior to the recognition of this clay; southern beds had been correlated with beds within 15 feet of the type Hounsfield in section. The relative thicknesses of the various deposits are consistent with the opinion that the volcanic vent was in southeastern United States. Lithologic sequences, particularly in central Ontario, Kentucky and Tennessee, are quite similar. It is improbable that the northern metabentonites represent two ash deposits of distinct but closely related ages, for no single section has two metabentonite beds, and only one bed is present in each region in which Black River rocks have been critically studied. A thick metabentonite and a thin "reworked ash" have been reported in a Kentucky section; if there be more than one late Black River southern metabentonite, the thick bed must be Hounsfield, for it is probable that only a thick bed would have extensive distribution.

It is most significant that the occurrence of the Hounsfield in the type Black River section defines its age and gives a middle Chaumont guide horizon throughout eastern North America.

Brief remarks were made by Prof. U. S. Grant.

LOWEST CAMBRIAN OF SOUTHERN QUEBEC [1]

BY T. H. CLARK

(*Abstract*)

The base of the "eastern sequence" of Cambrian rocks described by Keith in 1923 from northwestern Vermont is far better displayed in Canada than in the area described by him. Below the Cheshire quartzite (Lower Cam-

[1] Presented with the permission of thea Director, Geological Survey of Canada, Ottawa.

brian) considered by Keith to be the base of the Cambrian, lie in order the following undescribed formations:

West Sutton slate, 40 feet.
White Brook dolomite, 40 feet.
Pinnacle graywacke, 400 feet.
Call Mill slate, 25 feet.

The latter rests upon highly metamorphosed chlorite schist, presumably Precambrian. The Cheshire quartzite bears Lower Cambrian fossils, but the subjacent beds are barren. The absence of a basal conglomerate and the peculiar lithological types in this basal part of the Cambrian indicate unusual climatic and physiographic conditions attending the initiation of the Appalachian geosyncline in southern Quebec. The strata are strongly folded, but there is no evidence to show that the region was affected by more than one orogeny. As yet the time of folding is undetermined.

The lack of a basal conglomerate argues for a regolith of no great importance, and the graywacke points to rather rapid disintegration of therefore recently elevated uplands. The White Brook dolomite indicates a time during which the region was quiet, though slowly sinking, and receiving little or no detrital material from the shores. The succeeding formations repeat that succession fairly faithfully, in order, the West Sutton slate, the Cheshire quartzite, and the Rutland dolomite. The Cheshire quartzite lacks the abundant feldspar characterizing the graywacke, and, too, has a considerable amount of muddy matter, thus indicating that the second cycle of deposition was developed in a climate more tolerant of decomposition, and in a region of greater crustal instability, for the quartzite is probably more than 2,000 feet thick. The uppermost Cambrian bed is the Oak Hill slate (new name) which may or may not have been the forerunner of a third cycle whose other representatives have been lost by faulting and erosion.

Brief remarks were made by Prof. C. E. Gordon.

CORRELATION OF MONTANA ALGONKIAN FORMATIONS

BY C. H. CLAPP AND C. F. DEISS

(*Abstract*)

The publication of the first correlation table in 1906 by Walcott, and the description of the Cœur d'Alene and Philipsburg geology published in 1908 and 1915 by Calkins profoundly influenced all the workers in the Belt rocks of northwestern North America. Several men have objected to Walcott's and Calkins' correlation of the Belt formations in the different regions.

After several years' work in Glacier Park and in the Mission, Swan, and Lewis and Clark ranges, it became clear that the key to the problem lay in the area between Helena and Missoula, Montana. Preparatory to tracing the formations between these two regions, a detailed stratigraphic section was made of the rocks overlying the Wallace or Upper limestone of the western ranges. This section revealed 18,000 feet of argillites and quartzites compris-

ing five distinct lithologic formations which are designated the Missoula group. Details of lithologic character and thickness of these rocks are given. The thin Marsh shale of the Belt mountains which overlies the Helena limestone is merely the bottom of the many thousands of feet of argillite and quartzite of the Missoula group.

The continuity of deposits between Missoula and Helena disclose the significant fact that the Greyson, Spokane and Empire clastics of the Belt mountains, which in the type locality are much thicker than previously reported, thin to the west and northwest, being unrecognizable in the Cœur d'Alene region, so that the Newland and Helena limestones of the Belt mountains, separated by the Greyson, Spokane and Empire clastics, are correlated with one formation in the western ranges, the Wallace of the Cœur d'Alene area, and the Siyeh of Glacier Park. Nevertheless, the several thousand feet of red and green argillite and quartzite, of the Greyson, Spokane and Empire formations, may be traced westward to the Cœur d'Alene and Purcell mountains since they are represented by a relatively thin but persistent layer of red argillites throughout the western ranges of Montana and Glacier Park.

Presented by the junior author.

Brief remarks were made by Messrs. Edward Sampson and Charles E. Resser.

RING-DIKE OF THE OSSIPEE MOUNTAINS

BY LOUISE KINGSLEY [1]

(*Abstract*)

The Ossipee Mountains of central New Hampshire are a circular mass 9 miles in diameter. The lowland surrounding the mountains is underlain by Precambrian(?) Chatham granite, but within the mountains the rocks belong to a satellitic stock of the Late Paleozoic White Mountains alkaline batholith. The lower slopes of the mountains are underlain by a ring-dike of porphyritic hornblende quartz syenite 9 miles in diameter. The maximum width of the dike is 1 mile. Wherever the wall of the dike is exposed it is vertical. Within the ring-dike are volcanics into which it is intrusive. These volcanics consist of interbedded basalt, andesite, quartz porphyry, tuff, and breccia, which usually dip steeply toward the center of the mountains. In the very center of the mountains there is a lowland underlain by a coarse, pink biotite granite which has intruded the volcanics.

The structure indicates cauldron-subsidence. After the extrusion of the volcanics on the eroded surface of Chatham granite a circular fracture 9 miles in diameter developed and a cylinder of volcanics was down-faulted. At the same time a porphyritic hornblende syenite was intruded along the fault. Finally a stock of biotite granite intruded the central part of the area. Differential erosion has left the volcanics as a highland. The structure is analogous to that of the cauldron-subsidence of Glen Coe, Scotland, and to the ring-dikes of Mull.

[1] Introduced by Marland Billings.

ALTERATION AS AN END PHASE OF IGNEOUS INTRUSION IN SILLS ON LOVELAND MOUNTAIN, PARK COUNTY, COLORADO[1]

BY QUENTIN D. SINGEWALD[2]

(*Abstract*)

Sills occurring in the sedimentary rocks on the lower slope of Loveland Mountain belong to two rock types of slightly different ages. Monzonitic-diorite porphyry is the older, quartz monzonite porphyry, the younger. They are derived from the same magma reservoir, and are composed of different proportions of the same minerals. The groundmass of the quartz monzonite porphyry is very acidic. Although the sedimentary rocks between them are unaltered, both porphyries are altered. However, the monzonitic-diorite porphyry is comparatively fresh, whereas the quartz monzonite porphyry is intensely altered. The principal products of alteration are albitized plagioclase, sericite, penninite, epidote, iron-carbonate, and white carbonate. They were introduced progressively. Evidence indicates that the alteration of each porphyry was an end stage of its intrusion, and that the agents of alteration were in the magma itself or followed the same paths as the magma.

PETROGRAPHY AND PARAGENESIS OF GULF COAST SALT DOME, CAP ROCK MINERALS

BY LEVI S. BROWN[3]

(*Abstract*)

The usual flat top of a salt stock is succeeded by a characteristic rock series known collectively as the "cap." At the base the cap is anhydrite, which passes upward rather abruptly into gypsum and this latter to a brecciated fine-grained gray calcite, logged as "limestone." Sometimes the anhydrite changes directly to calcite, no gypsum intervening. In some caps the transition zone exhibits an abundance of free sulphur, in either a gypsum or calcite matrix.

This study was undertaken by and for the Freeport Sulphur Company, of Freeport, Texas. It was carried out principally during the last summer at Bryan Mound, one of the company's properties in Brazoria County, on the coast about 60 miles west and south of Galveston. Cores and core fragments from the cap of many coastal and a few interior domes were examined.

A detailed discussion of mineral content, original structures, secondary structures and evidences of alteration is accompanied and illustrated by a few lantern slides. Some of the observed data appear as additional evidence in support of existent salt dome beliefs. The principal conclusions derived are as follows: (1) The salt stock and cap represents an intrusion to a variable extent from unknown depths in response to enormous pressure acting in a vertical direction; (2) the anhydrite is a normal primary deposit in an evaporating sea; (3) the anhydrite of all Gulf Coast domes is equivalent in age; (4) some concrete evidence obtained opens an avenue to the probable

[1] Published with the permission of the Director of the United States Geological Survey.
[2] Introduced by Joseph T. Singewald, Jr.
[3] Introduced by E. H. Sellards.

determination of this age; (5) the calcite cap is a direct alteration of the underlying anhydrite; (6) the gypsum is formed by the hydration of the anhydrite.

EVALUATION OF BOUNDARIES IN THE MAPPING OF DRIFT-SHEETS

BY MORRIS M. LEIGHTON AND WILLIAM E. POWERS

(*Abstract*)

Little has been written concerning the criteria used in the detailed mapping of Pleistocene deposits, or in regard to the relative values of the various types of boundaries which are based on these criteria. This paper describes the use of such criteria in the mapping of the Wisconsin composite morainic system of northeastern Illinois. Various types of glacial boundaries, the data on which they are based and their relative degree of accuracy are discussed.

Presented by Mr. Powers.

FLOWAGE FOLDS

BY GEORGE W. BAIN [1]

(*Abstract*)

The limestones of the northern part of the Vermont marble belt lay beneath a shallow cover at the time they were folded. Fracture systems developed in them. The same beds in the southern part of the belt were deeply buried; fracture structures did not develop and flowage structures are characteristic. Folds and banded structures formed in the zone of flow are completely exposed for study in the many quarries of the Vermont Marble Company. These folds differ from normal types in variation in thickness of the beds included in them, in relative position of axes of drag folds to major structures and in change of dips of limbs as they approach the major axis. Such outstanding characteristic differences are described in the paper.

STRUCTURAL GEOLOGY OF CENTRAL MASSACHUSETTS

BY EUGENE CALLAGHAN [2]

(*Abstract*)

The Wachusett-Cold Brook tunnel northwest of Worcester, Massachusetts, affords a continuous section 14.2 miles long normal to the strike of the formations of the Highlands. A careful record of the geological conditions encountered in the excavation of the tunnel has been made by the geological staff of the Metropolitan District Water Supply Commission and forms the basis of this paper.

[1] Introduced by Charles P. Berkey.
[2] Introduced by Charles P. Berkey.

A very detailed section shows the relations of the formations, the Fitchburg granite, the Brimfield and Paxton schists, the Boylston schist and the Oakdale quartzite. The foliation of the schists appears to be parallel to the original bedding and dips at angles averaging less that 15 degrees for several miles of section forming broad folds. The Brimfield and Paxton schists are given significance as formations rather than rock types. A part of the Brimfield is designated tentatively as a separate formation, the Ware, because it was found to lie below the Paxton schist. The latter formation becomes thinner toward the west and is feldspathic. Data on nearly 2,000 joints, faults and veins have been analyzed. The Hubbardston appears to be the same granite as the Fitchburg.

Data bearing on the controversial question of the age of these formations has been gathered. The Fitchburg granite penetrates the Brimfield and Paxton schists and the Boylston schist representing the Worcester phyllite. Thus the igneous activity is of Carboniferous of later age, and the Paxton, Brimfield and Ware may be of Carboniferous age. The more advanced stage of metamorphism suggests that they may belong to an older series.

THRUST STRUCTURE OF THE CENTRAL WASATCH MOUNTAINS

BY A. A. L. MATHEWS [1]

(*Abstract*)

There are two or more systems of thrust-faulting in the central Wasatch Mountains. The first involves the Alta overthrust of the Cottonwood district, and the second, the horizontal displacement and the high and low angle overthrusts along the front of the Range.

The significance of the Wasatch fault-zone and its character bears directly on the location of reservoirs, dams and conduits, particularly in the eastern half of Salt Lake County.

STRUCTURE OF THE SAN CARLOS MOUNTAINS, MEXICO

BY LEWIS BURNETT KELLUM [2]

(*Abstract*)

The San Carlos Mountains are situated in the State of Tamaulipas, about 80 miles south of the Rio Grande. They are an isolated range rising out of the coastal plain midway between the eastern front of the Sierra Madre and the Gulf Coast. They cover an area of approximately 900 square miles.

These mountains structurally are an arcuate geanticline extending in an east-west direction with the convex side to the south. Superimposed on the major fold are a number of minor flexures parallel to the major trend of the range. The anticlinal structure has been greatly modified by the intrusion of numerous masses of igneous rock. These intrusions domed the strata contiguous to them. The evidence suggests that uplift of the San Carlos area commenced in late Cretaceous time.

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[1] Introduced by R. S. Bassler.

[2] Introduced by William H. Hobbs.

To the south of the San Carlos Mountains is the Sierra Tamaulipas in which the axis of folding is about north 10 degrees west. The two ranges are separated by a broad structural saddle.

In the Sierra Madre, 30 miles to the west, the axial trends are north 20 degrees to 40 degrees west. In the region south of Monterrey, Nuevo Leon, and extending west of Saltillo, Coahuila, there is a wide belt of intense east-west folding in the Sierra Madre Range. The San Carlos Mountains are believed to be the eastern continuation of this belt of cross-folding.

JOINT STUDIES IN THE SOUTHWEST AND THEIR BEARING ON TECTONIC HISTORY

BY FRANK A. MELTON [1]

(*Abstract*)

The material for this paper was obtained from several thousand measurements of joints in the hard strata of the nearly horizontal Carboniferous rocks of the Central Plains from Missouri to central Texas. Since the joints had but slightly as a rule, the most important relationships can well be shown merely by platting the directions of strike.

Considering only the strike, one notes the existence of many separate "sets" so distinct in their alignment that they may be arranged in broad groups or "systems."

When the number of joints with a given strike is considered the grouping into systems becomes more noticeable. The systems themselves become more definite and restricted. The following range of strike directions includes the most important regional systems:

North 15 degrees west to north 55 degrees west.
North 35 degrees east to north 75 degrees east.

The main northeast system strikes more toward the east in Kansas and Missouri than in Texas. It is roughly concave toward the southeast and, together with other factors such as the shift of the regional strike of the formations, points to the existence of a late Permian or post-Permian regional uplift of the combined area of Llanoria and the Ozark dome.

A prominent joint system radiates northward and northwestward from the front of the Ouachita Mountains. The individual faults in the so-called *en echelon* fault-belts of central Oklahoma are parallel in strike to the joints of this system in any restricted locality. The origins of the two features are doubtless closely related.

These new measurements strengthen the earlier conclusion that the more violent episodes in the Ouachita orogeny were of Permian or post-Permian age.

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[1] Introduced by Charles P. Berkey.

OPEMISKA SERIES [1]

BY CARL TOLMAN [2]

(*Abstract*)

Attention is called to a thick series of Precambrian sediments which have been found in the Opemiska district, Quebec, about 300 miles north of Montreal. Their great interest is centered in their apparent conformity within the basal volcanics which in this part of Quebec have been termed the Abitibi volcanics. Because of their position at the base of the Precambrian section, they are generally assumed to be Keewatin.

These sediments are here called the Opemiska series and appear to be at least 10,000 feet thick. They consist predominantly of arkose tending to be gritty and conglomeratic at a number of horizons. Very little argillaceous material is present and only one narrow bed of limestone was noted. Schistosity is generally developed throughout the series.

The basal volcanics and the associated Opemiska series have been closely folded with a trend approximating south 70 degrees east and with essentially vertical dip. An anticlinal axis is recognizable, in the southern part of the Opemiska Quadrangle, on both sides of which are outcropping bands of sediments about two miles in width. No structural discordance was distinguished between the sediments and the underlying and overlying volcanics. Near the base of the sediments are some interbedded andesitic flows. Immediately above the sediments the volcanic material is predominantly fragmental and mostly waterlaid. This is followed by lavas showing pillow structure.

GEOLOGY OF THE COCKEYSVILLE MARBLE BELT ALONG JAMES RIVER, CENTRAL VIRGINIA [3]

BY A. S. FURCRON [4]

(*Abstract*)

Between Lynchburg and Howardsville in central Virginia James River follows an anticlinal area of Precambrian rocks which have been referred by Jonas to the Glenarm series. They are bound on the west by the Catoctin Mountain border fault which forms a convenient eastern boundary for the Blue Ridge Province. On the upthrown (western) side of this fault occur Lynchburg gneiss with basic intrusives, Catoctin schist and infolded Lower Cambrian slate and quartzite.

The marble belt will average six miles in width and the formations are affected by many normal faults which usually separate it from extensive areas of Wissahickon schist to the east. Long northeast-southwest faults within the area are offset by cross-faults which also offset the border fault. The oldest exposed rocks are basaltic lava flows of unknown thickness now

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[1] Published by permission of the Director of the Geological Survey of Canada.
[2] Introduced by Chester K. Wentworth.
[3] Published by permission of the State Geologist of Virginia.
[4] Introduced by Anna I. Jonas.

altered to epidote-chlorite-hornblende greenstone. Over these flows occur about 200 feet of quartzite and schist here called the Mount Athos formation. The principal quartzite member, usually less than 100 feet thick, occurs generally near the middle of the formation and is enclosed by micaceous and talcose schists. Cockeysville marble rests upon this formation and is overlaid by Wissahickon schist and phyllite. It outcrops in narrow synclinal belts which are frequently interrupted by normal faults. The formation is at least 600 feet thick and consists of interlayered blue white and pink marbles, talcose and micaceous schists. Marble composes a large part of the formation in some localities and in other places it is greatly subordinate to schist.

Brief remarks were made by Mr. George W. Stose.

ICE ACTION IN TEAYS VALLEY, WEST VIRGINIA

BY JULIAN J. PETTY [1]

(*Abstract*)

Striated cobbles, with a lithology indicating an origin near at hand, are reported from the gravels of Teays Valley, an abandoned course of the Kanawha River. That the striation is due to ice action in the river at the time the stream gravels were deposited, is supported by the occurrence of evident ice-rafted cobbles in at least three tributary streams. The diversion of the Kanawha from Teays Valley was not due to the silting of the channel as is evidenced by diversion channels cut to the grade of Teays Valley before silt deposition. A continuous deposit of silt in the old valley extending to the vicinity of the glacial border in Ohio indicates that river ice action was probably not the cause of ponding.

GLACIATION ALONG THE PLATEAU FRONT IN NEW YORK

BY E. T. APFEL AND C. D. HOLMES [2]

(*Abstract*)

The north edge of the Allegheny Plateau across New York State was crossed several times by glacial ice. The present paper is a progress report on investigations as to the qualitative and quantitative control of the plateau margin on ice movement and glacial erosion and deposition. Undescribed interglacial gorges and other evidence indicate more than a single glacial stage.

The physiographic effect of the glaciations is best noted in valley shapes and relationships and in depositional phenomena. The direction of ice movement within the plateau was controlled to a greater or less extent by the larger valleys. Selective erosion of valleys trending with the general direction of movement increased this control and produced differences in the variously affected valleys which form a means of measuring the erosive effect of the ice on the plateau. The formation of some large valleys appears

[1] Introduced by Stephen Taber.
[2] Introduced by T. C. Hopkins.

to have been controlled by factors other than the general direction of ice movement. An extensive moraine of Wisconsin age, here named the *Cazenovia moraine*, lying a few miles within the plateau, can be traced across central New York. The course of this moraine and variations in its development reflect the physiographic control unusually well. Ice recession in this region was apparently not at a uniform rate, but by a series of stagnating termini to the several lobes, backed by still active ice. This resulted in a succession of kame terraces of slightly differing ages.

Presented by Mr. Holmes.

STRUCTURAL GEOLOGY OF KENTUCKY

BY WILLARD ROUSE JILLSON [1]

(*Abstract*)

A broad concept of the structural attitude of the older Paleozoic sediments in Kentucky visualizes a central longitudinal uplift—the Cincinnati Arch which strikes north 35 degrees east from the Tennessee line to Camp Nelson. Proceeding toward the Ohio River from Lexington this uplift has a biaxial crest striking in the composite almost due north. From this axial high all beds fall rapidly to the east and southeast as a crenulated monocline and to the west and southwest into a geosyncline, the southeastern tip of the central interior coal basin of the United States. The western flank of this geosyncline is marked by the crest of the Cumberland River arch, an anticline of only secondary importance to the Cincinnati uplift. This large minor structure following the course of the Cumberland River plunges northwestwardly from the Rutherford Dome in Tennessee across Kentucky along a line of axial strike of north 45 degrees west into the State of Illinois.

The outline of geologic structure thus presented eliminates the surficial (Pennsylvanian-Coal Measure) geosyncline of eastern Kentucky. It establishes a practically continuous line of major latitudinal faulting extending eastwardly from Shawneetown on the Ohio River in western Kentucky, to Warfield on the Tug River in eastern Kentucky. It exhibits further a highly faulted area involving some 2,000 or more square miles in western Kentucky, presents a line of faulting of axial strike northwestwardly across the Jessamine Dome and reaffirms the overthrust of the Pine Mountain in southeastern Kentucky. A belt of complex normal faulting which is more or less coincident with the periphery of the western Kentucky coal field is also indicated.

These data are derived from a manuscript structural map of Kentucky keyed on the top of the Chattanooga-New Albany-black (Devonian) shale. This plat, scaled 1:500,000, with 100-foot contour intervals, has been continuously in preparation by the writer since 1918. The apex of structure in Kentucky is a small area northeast of Camp Nelson on top of the Jessamine Dome of the Cincinnati Arch. At this point the top of the Devonian black shale is projected to 2,050 feet above sealevel. The lowest point in eastern Kentucky is near Argo in southeastern Pike county where the top of the

[1] Introduced by Nevin M. Fenneman.

Devonian shale is beneath 2,500 feet below sealevel. The lowest point in the western Kentucky coal basin is 3,850 feet below sealevel slightly west of Slaughter in Webster county, while on the west side of the Cumberland River Arch, the western tip of Kentucky in the Mississippi River bottoms is calculated to be 3,650 feet below sealevel. The maximum structural relief in Kentucky is, therefore, about 6,000 feet or 1 1/10 miles.

Read by title in the absence of the author.

GEOLOGY OF THE SAN JACINTO QUADRANGLE, CALIFORNIA

BY DONALD M. FRASER[1]

(*Abstract*)

A study of a part of the "Los Angeles Ranges" including areal, structural and geomorphologic considerations of the district.

The most widespread lithologic unit is the granitic rock of the San Jacinto batholith which makes up the core of the mountain. Approximately 12,000 feet of metamorphics, consisting of schist, crystalline limestone and gneiss, were intruded and tilted by the batholith. Following a long period of erosion late Tertiary and Quaternary sediments were deposited in the foothills.

The San Andreas Rift cuts the area north of the San Jacinto Mountains and the San Jacinto fault, the most active fault of the region, truncates their southwestern edge. It is between these great rift zones that the mountain block has been raised and is still suffering movement. These zones are of special importance at the present time for they are crossed by proposed routes of the Hoover Dam-Southern California aqueduct.

Benches, cut on granite, are found at elevations of close to 5,000 feet. Some of these are thought to be rock pediments now in the process of dissection. Probably certain benches represent old erosion levels developed between successive stages of uplift of the San Jacinto block.

Read by title in the absence of the author.

DESPOSITION FEATURES OF THE "PARTING" QUARTZITE NEAR ALMA, COLORADO[2]

BY QUENTIN D. SINGEWALD[3]

(*Abstract*)

The "Parting" quartzite, whose name is derived from its stratigraphic position between two limestone formations, occurs in an extensive area of the Park Range of central Colorado. In the Alma district, the formation has two lithologic facies. A predominantly sandy facies occurs where the formation is thick, and a limy facies, where it is thin. The variations in thickness are due to variations in amount of material deposited. No material was deposited over part of the area. An erosional unconformity separates the

[1] Introduced by Charles P. Berkey.

[2] Published with the permission of the Director of the United States Geological Survey.

[3] Introduced by Joseph T. Singewald, Jr.

formation from the underlying limestone. A gradational contact with the overlying limestone exists at places. Deposition took place in a shallow transgressing sea. Currents were fairly swift and frequently changed their direction. Areas of thick, sandy sediments represent former channels of deposition that probably were shoals.

Read by title.

AVAILABLE RELIEF AS A FACTOR OF CONTROL IN THE PROFILE OF A LAND FORM

BY WALDO S. GLOCK [1]

(Abstract)

Observation supplemented by extensive study of topographic maps has shown that available relief, that is, the vertical distance from the initial upland level down to initial grade, is an important factor of control in the profile of a land form during the progress of the geographic cycle. If the available relief is less than 200 to 300 feet, valley flats are developed before the original upland is destroyed; in other words, upper flats and lower flats will exist at the same time. If the available relief exceeds 200 to 300 feet the uplands are entirely destroyed before the lowlands begin to develop; the divides are reduced below their original positions, and the amount of reduction is proportional to the amount by which the available relief exceeds 200 to 300 feet.

Certain factors—such as rock texture, composition and structure, rate of uplift and climate—modify to some extent the profile development as outlined. It appears that aridity and cold serve to increase the amount of relief necessary to eliminate the upland prior to the appearance of the lowland.

If the above observations hold, the question may be raised as to whether certain parts of an uplifted peneplain can be preserved while a lower partial peneplain is being developed at an elevation greater than 200 to 300 feet below the higher peneplain.

Read by title.

SPONTANEOUS EXPANSION

BY GEORGE W. BAIN [2]

(Abstract)

Marble in many parts of the deposit through Pittsford and Wallingford, Vermont, expands spontaneously as new free surface is produced by quarrying. Expansion of stone is observed only at distances exceeding 20 feet from a naturally produced free surface. Studies indicate expansion is volumetric, although exact measurements could be made in only one direction; these were made to an accuracy of one ten thousandth of an inch in three feet and indicated a

[1] Introduced by J. E. Carman.
[2] Introduced by Charles P. Berkey.

linear expansion of 0.0067 inch per foot. Presence of mixed ice and water in the quarries indicate constant temperature conditions.

Two forms of expansion were observed. One form is instantaneous and behaves according to the elastic curve formula:

$$E\,I\,\frac{d^2y}{dx^2} = M$$

Where:

E = Modulus of elasticity
I = Moment of inertia of deformed body
x = Distance of point of support from applied load
y = Deformation due to applied load
M = Moment of applied load about fixed end

The second expansion is dependent on time and is a pressure hysteresis, similar to the thermal hysteresis discovered in 1906; change is given by the equation:

$$\text{Log } y = m \text{ Log } x - C$$

Where:

y = Time elapsed since production of free surface
x = Expansion in time y
M and C = Constants dependent on distance from free surface and modulus of elasticity

Expansion is believed to be due to compression of the rocks at the time they were folded. Absence of expansion in the upper twenty feet is believed to be due to relief of hysteresis.

Read by title.

The sectional meeting adjourned at approximately 5 o'clock.

Regular Session of Wednesday Afternoon

The afternoon session was opened at 2:10 o'clock in Room 22, Mining Building, with Vice-President Nelson H. Darton in the chair.

TITLES AND ABSTRACTS OF PAPERS

SEA-BOTTOM SAMPLES FROM THE CABOT STRAIT EARTHQUAKE ZONE

BY EDWARD M. KINDLE

(*Abstract*)

The paper deals with bottom samples obtained during the repairs to cables broken by the earthquake of November 18, 1929. These belong in the class of terriginous deep-sea deposits and represent a maximum depth of 2,000 fathoms. The study includes a statement of the macroscopic characteristics of the samples, mechanical analysis showing percentage of sand silt and clay for selected samples and the names of the microscopic minerals present in several samples.

The biological examination of the samples has shown a few diatoms, 25 species of foraminifera and one pelecypod.

Much of the material in the samples is considered to represent ice transportation. Observations are made on the probable effect of the earthquake in disturbing the equilibrium of deposits of this type and in bringing about a considerable shifting of bottom sediments near the fault-lines.

The progressive breaking of the cables in a southerly direction from the epicenter, as determined by the Dominion Observatory, is interpreted as due to submarine landslides which developed under the influence of bottom currents produced chiefly by the piling up landwards of surface waters under the influence of the storm in progress at the time of the earthquake.

STRUCTURES IN ADIRONDACK MAGNETITES

BY D. H. NEWLAND

(*Abstract*)

Adirondack low-titanium magnetites not infrequently exhibit structural forms like those of folded sediments, although their environment is chiefly igneous of the normal plutonic magmas or of such magmas associated with highly injected gneisses. Thus, the Lyon Mountain deposits enclosed by granite for the most part lie in pitching synclinal troughs, connected end to end by a reverse fold or anticlinal. At Mineville some very complex structures are encountered that appear to combine the effects of folding, stretching and plastic disruption, whereas other bodies near by show little variations from a tabular or lenticular shape. The Hammondville district provides similar examples of anomalous conditions. Recent evidence seems to indicate that these in the main are relict or inherited structures from antecedent Grenville strata which have been largely absorbed or revamped by the invading ore magmas. The syenite and granite country rocks in their emplacement have followed the planes of bedding and were intruded as a series of sills in the later stages of Grenville folding, if not in some instances after it had been completed.

The magnetites were introduced in part with the intrusive magmas and in part by pegmatitic after-effects of the invasion. The latter process was probably the more important; metasomatic action was an accompaniment, with the ores and the pegmatites finding the silicate members of the Grenville, rather than the limey, most open to their attack. Where the invasions have crossed the structural lines and have reached the limestones they have led to contact deposits, in which the magnetite is associated with garnet, hornblende, pyrite, etcetera, too lean and irregular for working under present conditions.

SIGNIFICANCE OF TRANSGRESSION OF CRETACEOUS SEA

BY FRANK BURSLEY TAYLOR

(*Abstract*)

The distribution of the lands transgressed by the Cretaceous Sea, as represented on a Mercator map by Schuchert, shows characteristics which agree with Suess' claim that the change of ocean level was not eustatic or world-

wide and hence everywhere uniform in amount, such as would be caused by a sinking of the ocean floor, but was due to a slight change in the oblate figure of the ocean causing the water to fall away from the polar regions and at the same time to rise to higher levels in the equatorial belt. The paper dwells briefly on certain features of Schuchert's map and points out the relation of this kind of change to the writer's theory of sliding continents and the formation of the Tertiary mountain ranges. The force which caused the great transgression is identified as the same force that caused the sliding of the continental crust sheets, both being due to a permanently augmented tidal force, but finding expression in results of very different kinds and qualities—one responding quickly with no cumulative effect, the other very slowly with enormous accumulation of effects.

Read by title in the absence of the author.

ORIGIN OF DOMES IN LINCOLN AND MITCHELL COUNTIES, KANSAS

BY KENNETH K. LANDES AND J. W. OCKERMAN

(*Abstract*)

The Cretaceous rocks of north central Kansas contain a number of circular and elliptical domes with dips up to 4 degrees and closures as great as 90 feet. Surface observations show increased structural relief downward, whereas well records give no evidence of doming in the Permian and older sediments. Various theories of origin are considered, but several, such as salt leaching, must be rejected because of discordant subsurface data. Differential compaction of the Cretaceous sediments over buried hills is inadequate. The authors tentatively suggest that the domal structures are due to initial deposition of the Cretaceous sediments conformable to the surface of Permian hills.

Brief remarks were made by Messrs. Marcus I. Goldman, Parker D. Trask, and John L. Rich.

OIL TRAPS

BY VICTOR ELVERT MONNETT

(*Abstract*)

The earliest classifications of oil accumulations emphasized the structural position and gave little attention to any of the other factors which determine the location of such occurrences. The importance of variations in rock porosity was recognized only when new oil pools were found in positions not in agreement with the structural theory.

The classification of oil traps presented in this paper attempts to evaluate the relative importance of both rock structure and rock openings. The rock structures are divided into: (1) Homoclines, (2) anticlines and synclines, (3) domes, and (4) unconformities, with a number of subtypes and examples of each. Rock openings are grouped as: (1) Solution cavities, (2) dolomitization, (3) joints and faults, (4) brecciated zones, (5) original porous lenses,

(6) differential cementation, and (7) residual material. No consideration is given to the manner, distance, date and rate of migration since the classification is based upon actual petroleum occurrences regardless of source and migration.

SAINT LAWRENCE (CABOT STRAIT) SUBMARINE TROUGH

BY FRANCIS P. SHEPARD

(*Abstract*)

Since the Grand Banks earthquake of November, 1929, three well-known students of earthquakes have independently expressed the conclusion that the submarine trough which extends down the Saint Lawrence and out through Cabot Strait is a graben. The principal evidence for this contention is that the breaks in the cables which accompanied the earthquake were for the most part directly outside the submarine trough. However, there are plenty of valleys on the land which are subject to occasional earthquakes and yet are clearly due to erosion. Since in this case the earthquakes only bordered the outer margin of the depression, it seems very advisable to examine all possible evidence to see whether erosion could not have produced this feature.

It happens that the trough is similar in form to many other submarine troughs which occur on the continental shelves along glaciated coasts. These troughs are not found except off glaciated territory. In many cases they are continuations of glacial fiords and resemble them greatly. That their present form is due to glaciation is a natural conclusion.

During the past summer an investigation of the Saint Lawrence trough was made. Soundings in Cabot Strait and field examination of the sides of the strait were made to supplement other sources of information. Nothing was found to substantiate the fault origin of the trough, but data compiled from various sources appear to favor a glacial origin.

Brief remarks were made by Prof. Douglas Johnson.

DINWOODY GLACIERS

BY CHESTER K. WENTWORTH AND DAVID M. DELO

(*Abstract*)

The little-known glacier system which lies along the crest of the Wind River Range in west central Wyoming appears to be the most extensive compact glacier group in the Rocky Mountains south of the Canadian boundary, not excepting the groups in Glacier National Park, and is surpassed in area only by the great radiating systems of Mount Rainier, Mount Baker and possibly other more northerly peaks of the Cascade Range.

The Wind River system extends for 15 miles along the northeast side of the range with only four short breaks. The total area of ice and snow is about 15 square miles, of which over 8 square miles drains to Dinwoody Creek. So far as known, this is much the largest area of ice draining to one headwater stream anywhere in the Rocky Mountains of the United States.

Several other glaciers of over a square mile in extent are found in the basin of Bull Lake Creek and two glaciers lie on the southwest side of the range in the basin of Green River. Two principal Dinwoody glaciers, here named North Gannett and East Gannett glaciers, are described as a result of a brief visit in July, 1930. The name West Gannett Glacier is applied to the largest of the Green River glaciers, the three Gannett glaciers being clustered on three sides of Gannett Peak, the highest point in Wyoming.

Brief remarks were made by Prof. Albert O. Hayes.

STRUCTURE AND STRATIGRAPHY OF A PORTION OF THE MINNESOTA PRECAMBRIAN

BY U. S. GRANT AND J. T. STARK

(*Abstract*)

Detailed mapping of a small Precambrian area in northeastern Minnesota has yielded results differing materially from earlier maps, descriptions and sections of this region. The formations, regarded as Lower-Middle Huronian in age, consist of a conglomerate grading upward into tuffaceous graywacke and slates which in turn are overlain by a coarse volcanic agglomerate and a finer grained hornblende tuff. The whole series has been overturned, cut by diabase dikes and faulted.

Presented by Mr. Stark.

LAVAS OF ELGON

BY E. J. WAYLAND AND N. L. BOWEN

(*Abstract*)

Mount Elgon is a volcanic pile rising to an altitude of 14,140 feet on the border between Uganda and Kenya in Africa. The volcanic rocks are of Tertiary age and consist of a thick series of pyroclastics and lava flows resting in a nearly horizontal attitude on ancient gneiss. The mass has been deeply dissected and great cliffs of massive agglomerate are a prominent feature of the topography, especially on the western slopes. The lavas are of strongly sodic affinities, the principal types being nephelinites and melilite-nephelite basalts. An analysis of each of these types has been made.

Presented by the senior author.

Brief remarks were made by Messrs. Andrew C. Lawson and W. E. Wrather.

DEFORMED ORBITOIDS

BY WILLARD BERRY[1]

(*Abstract*)

In the course of my work on the "Tertiary Foraminifera of Peru," I have found several orbitoids which have suffered deformation and lived or

[1] Introduced by Edward W. Berry.

healed after the accident. These accidents must have been very rare because in studying several thousand specimens only two deformed specimens have been found. One specimen has suffered a damaged margin and has healed. The other has developed in three planes instead of the usual one. They are discussed briefly and figured with particular emphasis on the deformation.

STORM ROLLERS[1]

BY GEORGE HALCOTT CHADWICK

(Abstract)

The current concept that zones of "storm rollers," often mismentioned as "concretions," are of rare and local occurrence, in the Upper Devonian of New York State, has been dissipated by field work in Chenango and Broome counties, where the phenomenon is wide-spread and involves at one point or another practically all of the principal Upper Devonian formations. There is need for monographic study of this remarkable display of these features, which almost always lie close to the transition from marine to continental clastics, and which in some cases can hardly be wave work.

ONEONTA FADE-OUT[1]

BY GEORGE H. CHADWICK AND JOSEPH W. MONAHAN[2]

(Abstract)

No satisfactory account has been given hitherto of the manner of transition from the continental Oneonta Red Beds and flagstones into the marine Ithaca gray shales, which occurs in Chenango County, New York, as John M. Clarke long ago announced. The stratigraphic correlations of Clarke moreover were erroneous, in correcting which H. S. Williams fell into the error of injecting the Oneonta as a wedge. The fading out of nearly 500 feet of Oneonta strata from red and green delta stuffs into ordinary marine sediments of the upper Ithaca (*Spirifer mesistrialis* division) in the short space from the Chenango to the Tioughnioga valleys is sufficiently instructive to deserve extended description.

CATSKILL FORMATION[1]

BY GEORGE HALCOTT CHADWICK

(Abstract)

The name Catskill, as applied to a continental facies of the Upper Devonian in New York and Pennsylvania, has come to imply a wide-spread equivalence of these beds which does not exist. Field studies are now closing the gap in correlation between the type section in the Catskill Mountain front west of the Hudson River in Greene County, New York, and the marine beds of central New York, with the surprising result that much or all of it is proving

[1] Presented by courtesy of the Cities Service Company.

[2] Joseph W. Monahan was killed near Port Byron, New York, on December 1, 1930, by an accident to his automobile, while carrying on his geological work. He was 24 years old—just beginning a life of great promise.—G. H. C.

to be of "Portage" (Enfield) age, thus putting the Catskill *below the Chemung* instead of above it! The so-called "Catskill" on other meridians, of various horizons, must therefore be sharply discriminated.

Brief remarks were made by Messrs. John L. Rich, J. W. Beede, and E. M. Kindle.

RESOLUTION OF THANKS ADOPTED BY THE SESSION

The following resolution of thanks was read by Dr. Nelson H. Darton, and unanimously adopted:

"Resolved: That the Geological Society of America wishes to convey to the Local Committee and other citizens of Toronto its high appreciation of their many courtesies, the fine facilities, and the delightful entertainments which have made the Toronto meeting one of its most agreeable reunions."

RESOLUTION OF APPROVAL OF ACTS OF THE COUNCIL

The following resolution, duly made and seconded, was unanimously adopted:

"Resolved: That all acts and proceedings of its Council, during the year 1930, be and they hereby are approved, ratified, confirmed, and adopted by the membership of the Geological Society of America.

Vice-President Darton then announced that the business, the scientific sessions, and other activities of the annual meeting of 1930 had been completed, and on motion the forty-third annual meeting adjourned at 5 p. m.

CHARLES P. BERKEY,
Secretary.

RESOLUTION OF THANKS ADOPTED BY THE COUNCIL [1]

"Resolved: That the Council of the Geological Society of America formally express to the local committee in charge of arrangements for the annual meeting of the Geological Society of America held at Toronto, Ontario, December 29-31, 1930, its deep appreciation of the conspicuously successful efforts of the local committee to make the meeting one long to be remembered for comfort and convenience, for the dignity of its proceedings, and for the facility with which it was conducted.

"Although one of the largest meetings in the Society's history, there was no sense of crowding. Although the general sessions and the sectional meetings were very fully attended, there was ample space and ready accessibility. Hospitality, official and personal, was everywhere dignified and generous, and assumed the most attractive forms.

"It is realized that all of this meant foresight, thorough planning, complete cooperation, and a great amount of thought and effort on the part of the local

[1] December 31.

committee, yet it was all so well done that the members of the Society and its guests were not allowed to sense the labor of preparation that lay in the background. They felt only that they were welcome guests, whose every wish and comfort had been anticipated and provided for.

"The Council, as the official representative of the Society, desires by this resolution to indicate in some slight measure its appreciation of the quality of the hospitality extended by its hosts, the University of Toronto and the local committee."

W. C. MENDENHALL,
CHARLES P. BERKEY,
Committee.

REGISTER OF THE TORONTO MEETING

FELLOWS

FRANK D. ADAMS
WILLIAM M. AGAR
H. R. ALDRICH
HAROLD L. ALLING
GEORGE H. ASHLEY
H. FOSTER BAIN
SYDNEY H. BALL
FLORENCE BASCOM
R. S. BASSLER
ALAN M. BATEMAN
W. S. BAYLEY
E. F. BEAN
J. W. BEEDE
CHARLES H. BEHRE, Jr.
CHARLES P. BERKEY
ARTHUR BEVAN
MARLAND P. BILLINGS
N. L. BOWEN
JOHN S. BROWN
THOMAS C. BROWN
E. L. BRUCE
A. F. BUDDINGTON
E. M. BURWASH
M. R. CAMPBELL
CHARLES CAMSELL
J. ERNEST CARMAN
GEORGE H. CHADWICK
ROLLIN T. CHAMBERLIN
T. H. CLARK
HERDMAN F. CLELAND
A. P. COLEMAN
W. H. COLLINS
R. J. COLONY
CHARLES W. COOK
C. S. CORBETT
H. N. CORYELL
EDGAR R. CUMINGS
NELSON C. DALE
NELSON H. DARTON
E. DE GOLYER
J. S. DE LURY
JOHN A. DRESSER
HARRY N. EATON
OLIVER C. FARRINGTON
NEVIN M. FENNEMAN
H. G. FERGUSON
CHARLES R. FETTKE
RICHARD M. FIELD
AUGUST F. FOERSTE
WILBUR G. FOYE
J. J. GALLOWAY
S. L. GALPIN
GEOFFREY GILBERT
JAMES GILLULY

L. C. Glenn
Marcus I. Goldman
Clarence E. Gordon
Charles N. Gould
U. S. Grant
L. C. Graton
John W. Gruner
E. C. Harder
Chris A. Hartnagel
Albert O. Hayes
K. C. Heald
Edwin T. Hodge
J. E. Hoffmeister
Oliver B. Hopkins
W. V. Howard
B. F. Howell
George S. Hume
Walter F. Hunt
E. C. Jacobs
Douglas Johnson
George F. Kay
Arthur Keith
Paul F. Kerr
E. M. Kindle
Virgil R. D. Kirkham
E. H. Kraus
Henry B. Kummel
George F. Kunz
Kenneth K. Landes
Alfred C. Lane
E. S. Larsen, Jr.
Andrew C. Lawson
Morris M. Leighton
J. Volney Lewis
Chester R. Longwell
J. T. Lonsdale
F. B. Loomis
R. S. Lull
J. H. C. Martens
George C. Martin
Kirtley F. Mather
Edward B. Mathews
William J. McCaughey
W. C. Mendenhall
J. B. Mertie, Jr.
Herbert E. Merwin
O. E. Meinzer
Benjamin L. Miller
Hugh D. Miser
V. E. Monnett
E. S. Moore
Raymond C. Moore
David H. Newland
A. A. Olsson
John J. O'Neill
W. A. Parks
A. L. Parsons
R. A. F. Penrose, Jr.
Edward H. Perkins
Alexander H. Phillips
F. B. Plummer
Sidney Powers
Percy E. Raymond
Chester A. Reeds
John B. Reeside, Jr.
Charles E. Resser
John L. Rich
Stephen Richarz
H. Ries
Joseph K. Roberts
Austin F. Rogers
Bruce Rose
Clarence S. Ross
Rudolf Ruedemann
Edward Sampson
W. T. Schaller
Walter H. Schoewe
I. D. Scott
E. H. Sellards
F. P. Shepard

H. W. Shimer
Joseph T. Singewald, Jr.
E. M. Spieker
T. W. Stanton
Chester Stock
R. W. Stone
George W. Stose
A. C. Swinnerton
W. T. Thom, Jr.
F. T. Thwaites
I. P. Tolmachoff
Parker D. Trask
A. C. Trowbridge
W. H. Twenhofel
E. O. Ulrich
Frank R. Van Horn
O. D. Von Engeln
T. L. Walker
Freeman Ward
Carroll H. Wegemann
Lewis G. Westgate
David White
A. N. Winchell
W. E. Wrather

FELLOWS-ELECT

Willard Berry
Richard E. Fuller
G. E. Goodspeed
James E. Hawley
James D. Sisler
Percival S. Warren
J. Marvin Weller
Bradford Willard

In addition to the foregoing there were registered at the meeting 353 members of affiliated societies and visitors, making a total of 519.

Lists of Former Officers and Meetings, with Dates

By recommendation of the Council, a complete list of past officers, with the dates of their services, and also the places at which meetings were held, are given below.

PRESIDENTS

1889. James Hall
1890. James D. Dana
1891. Alexander Winchell
1892. G. K. Gilbert
1893. J. William Dawson
1894. T. C. Chamberlin
1895. N. S. Shaler
1896. Joseph Le Conte
1897. Edward Orton
1898. J. J. Stevenson
1899. B. K. Emerson
1900. G. M. Dawson
1901. C. D. Walcott
1902. N. H. Winchell
1903. S. F. Emmons
1904. J. C. Branner
1905. Raphael Pumpelly
1906. I. C. Russell
1907. C. R. Van Hise
1908. Samuel Calvin
1909. Grove K. Gilbert
1910. Arnold Hague
1911. William M. Davis
1912. H. L. Fairchild
1913. Eugene A. Smith
1914. George F. Becker
1915. Arthur P. Coleman
1916. John M. Clarke

1917.	Frank D. Adams	1924.	Waldemar Lindgren
1918.	Whitman Cross	1925.	William B. Scott
1919.	J. C. Merriam	1926.	Andrew C. Lawson
1920.	I. C. White	1927.	Arthur Keith
1921.	James F. Kemp	1928.	Bailey Willis
1922.	Charles Schuchert	1929.	Heinrich Ries
1923.	David White	1930.	R. A. F. Penrose, Jr.

VICE-PRESIDENTS

1889.	James D. Dana	Alexander Winchell
1890.	J. S. Newberry	A. Winchell
1891.	G. K. Gilbert	T. C. Chamberlin
1892.	J. W. Dawson	T. C. Chamberlin
1893.	T. C. Chamberlin	J. J. Stevenson
1894.	N. S. Shaler	G. H. Williams
1895.	Joseph Le Conte	Charles H. Hitchcock
1896.	Charles H. Hitchcock	Edward Orton
1897.	J. J. Stevenson	B. K. Emerson
1898.	B. K. Emerson	G. M. Dawson
1899.	G. M. Dawson	C. D. Walcott
1900.	C. D. Walcott	N. H. Winchell
1901.	N. H. Winchell	S. F. Emmons
1902.	S. F. Emmons	J. C. Branner
1903.	Arnold Hague	H. S. Williams
1904.	H. S. Williams	Samuel Calvin
1905.	Samuel Calvin	W. M. Davis
1906.	W. M. Davis	E. A. Smith
1907.	J. S. Diller	A. P. Coleman
1908.	George F. Becker	A. C. Lawson
1909.	Frank D. Adams	John M. Clarke
1910.	Charles Schuchert	A. P. Low
1911.	William North Rice	
1912.	Israel C. White	
1913.	James F. Kemp	R. D. Salisbury
1914.	Waldemar Lindgren	Horace B. Patton
1915.	L. V. Pirsson	H. P. Cushing
1916.	J. P. Iddings	H. F. Reid
1917.	A. C. Lawson	W. D. Matthew
1918.	Bailey Willis	Frank Leverett
1919.	R. A. F. Penrose, Jr.	Herbert E. Gregory
1920.	George P. Merrill	W. G. Miller
1921.	J. B. Woodworth	Arthur Keith
1922.	Henry S. Washington	Robert T. Hill
1923.	W. H. Hobbs	W. H. Emmons
1924.	William A. Parks	Johan A. Udden
1925.	Reginald W. Brock	Marius R. Campbell

* Not including ex-officio Vice-Presidents representing the affiliated Societies.

1926.	Heinrich Ries	Lewis G. Westgate
1927.	Charles K. Leith	Douglas W. Johnson
1928.	Alfred C. Lane	William H. Collins
1929.	W. S. Bayley	U. S. Grant
1930.	N. H. Darton	Florence Bascom

TREASURERS

1889-1891.	H. S. Williams
1892-1906.	I. C. White
1907-1917.	W. B. Clark
1917-	E. B. Mathews

SECRETARIES

1889-1890.	John J. Stevenson
1891-1906.	H. L. Fairchild
1907-1922.	E. O. Hovey
1923-	Charles P. Berkey

EDITORS

1890-1892. W J McGee

1893- J. Stanley-Brown

COUNCILORS

1889.	J. W. Powell	J. S. Newberry	C. H. Hitchcock
1890.	J. W. Powell	G. M. Dawson	
1891.	George M. Dawson	J. C. Branner	
1892.	N. H. Winchell	H. S. Williams	
1893.	E. A. Smith	C. D. Walcott	
1894.	F. D. Adams	I. C. Russell	
1895.	R. W. Ells	C. R. Van Hise	
1896.	B. K. Emerson	J. M. Stafford	
1897.	J. S. Diller	W. B. Scott	
1898.	Robert Bell	M. E. Wadsworth	
1899.	W. M. Davis	Joseph A. Holmes	
1900.	W. B. Clark	A. C. Lawson	
1901.	Samuel Calvin	Arthur P. Coleman	
1902.	C. W. Hayes	J. P. Iddings	
1903.	R. D. Salisbury	J. E. Wolff	
1904.	John M. Clarke	George P. Merrill	
1905.	H. M. Ami	J. F. Kemp	
1906.	A. C. Lane	David White	
1907.	H. E. Gregory	H. F. Reid	
1908.	H. P. Cushing	H. B. Patton	
1909.	G. O. Smith	H. S. Washington	
1910.	J. B. Woodworth	C. S. Prosser	
1911.	A. H. Purdue	Heinrich Ries	
1912.	S. W. Beyer	Arthur Keith	
1913.	Whitman Cross	W. G. Miller	
1914.	R. A. F. Penrose, Jr.	W. W. Atwood	
1915.	Charles K. Leith	Thomas L. Watson	
1916.	Frank B. Taylor	Charles P. Berkey	
1917.	Arthur L. Day	William H. Emmons	
1918.	Joseph Barrell	R. A. Daly	

1919.	William S. Bayley	Eugene W. Shaw
1920.	T. W. Vaughan	George F. Kay
1921.	L. C. Graton	G. D. Louderback
1922.	E. S. Bastin	L. G. Westgate
1923.	E. O. Hovey	A. H. Brooks
	Charles Camsell	J. A. Bownocker
1924.	Fred. E. Wright	William H. Twenhofel
1925.	U. S. Grant	Florence Bascom
1926.	Nelson H. Darton	George H. Ashley
1927.	H. Foster Bain	Henry B. Kummel
1928.	George R. Mansfield	William E. Wrather
1929.	Herdman F. Cleland	Elwood S. Moore
1930.	W. C. Mendenhall	W. J. Mead

ANNUAL AND SEMI-ANNUAL MEETING PLACES

1888. Ithaca, New York.
1889. Toronto, Canada, August.
New York City, December.
1890. Indianapolis, Indiana, August.
Washington, D. C., December.
1891. Washington, D. C., August.
Columbus, Ohio, December.
1892. Rochester, New York, August.
Ottawa, Canada, December.
1893. Madison, Wisconsin, August.
Boston, Massachusetts, December.
1894. Brooklyn, New York, August.
Baltimore, Maryland, December.
1895. Springfield, Massachusetts, August.
Philadelphia, Pennsylvania, December.
1896. Buffalo, New York, August.
Washington, D. C., December.
1897. Detroit, Michigan, August.
Montreal, Canada, December.
1898. Boston, Massachusetts, August.
New York City, December.
1899. Columbus, Ohio, August.
Washington, D. C., December.
1900. New York City, June.
Albany, New York, December.
1901. Denver, Colorado, August.
Rochester, New York, December.
1902. Pittsburgh, Pennsylvania, July.
Washington, D. C., December.
1903. St. Louis, Missouri, December.
1904. Philadelphia, Pennsylvania, December.
1905. Ottawa, Canada, December.
1906. New York City, December.

1907. Albuquerque, New Mexico, December.
1908. Baltimore, Maryland, December.
1909. Cambridge and Boston, Massachusetts, December.
1910. Pittsburgh, Pennsylvania, December.
1911. Washington, D. C., December.
1912. New Haven, Connecticut, December.
1913. Princeton, New Jersey, December.
1914. Philadelphia, Pennsylvania, December.
1915. Leland Stanford, Jr., University, California, August.
Washington, D. C., December
1916. Albany, New York, December.
1917. St. Louis, Missouri, December.
1918. Baltimore, Maryland, December.
1919. Boston, Massachusetts, December.
1920. Chicago, Illinois, December.
1921. Amherst, Massachusetts, December.
1922. Ann Arbor, Michigan, December.
1923. Washington, D. C., December.
1924. Ithaca, New York, December.
1925. New Haven, Connecticut, December.
1926. Madison, Wisconsin, December.
1927. Cleveland, Ohio, December.
1928. New York City, December.
1929. Washington, D. C., December.
1930. Toronto, Canada, December.

ARTICLES OF INCORPORATION AND BY-LAWS OF THE GEOLOGICAL SOCIETY OF AMERICA, INCORPORATED

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ARTICLES OF INCORPORATION

CONSENT OF THE UNIVERSITY OF NEW YORK

THE UNIVERSITY OF THE STATE OF NEW YORK

STATE OF NEW YORK,
County of Albany, ss:

Pursuant to the provisions of Section 11, Article 2, of the Membership Corporations Law, as amended by Chapter 722 of the Laws of 1926, consent is hereby given to the filing of the annexed certificate of incorporation of "GEOLOGICAL SOCIETY OF AMERICA" as a membership corporation.

This consent, however, shall in no way be construed as an approval by the Education Department, Board of Regents or Commissioner of Education of the purposes and objects of this corporation, nor shall it be construed as giving the officers and agents of this corporation the right to use the name of the Education Department, Board of Regents or Commissioner of Education in its publications and advertising matter.

IN WITNESS WHEREOF, I, Frank P. Graves, Commissioner of Education of the State of New York, for and on behalf of the State Education Depart-

ment, do hereunto set my hand and affix the seal of the State Education Department, at the city of Albany, this 2nd day of May, 1929.

[SEAL OF THE UNIVERSITY OF THE STATE OF NEW YORK.]

(Signed) FRANK P. GRAVES,
Commissioner of Education.

APPROVAL OF THE JUSTICE OF THE SUPREME COURT

NEW YORK SUPREME COURT,
New York County, ss:

IN THE MATTER OF THE APPLICATION FOR THE INCORPORATION OF THE GEOLOGICAL SOCIETY OF AMERICA UNDER THE NAME OF "THE GEOLOGICAL SOCIETY OF AMERICA, INC.," PURSUANT TO THE MEMBERSHIP CORPORATIONS LAW.

I hereby approve the within Certificate of Incorporation, pursuant to the provisions of Article II, Section 10 of the Membership Corporations Law of the State of New York.

(Signed) HENRY L. SHERMAN,
Justice of Supreme Court of the State of New York for the First Judicial District.

Dated: New York, April 17, 1929.

CERTIFICATE OF INCORPORATION OF THE GEOLOGICAL SOCIETY OF AMERICA, INC., PURSUANT TO THE MEMBERSHIP CORPORATIONS LAW.

We, the undersigned, desiring to form a membership corporation, pursuant to the Membership Corporations Law, and being all the members of a committee duly authorized as required by said law to incorporate the Geological Society of America (an existing unincorporated society), do hereby certify as follows:

1. The name of the proposed corporation is: "The Geological Society of America, Inc."

2. The purpose for which it is to be formed is: "The Promotion of the Science of Geology in North America."

3. The territory in which the operations of the corporation are to be principally conducted is: All of the States, Territories, Colonies and Dependencies of the United States of America.

4. The principal office of the corporation shall be located in the city of, county of, and State of New York.

5. The number of its directors (to be known as "Councilors") shall be seventeen (17).

6. The names and post office addresses of the persons constituting the Board of Directors (to be known as "Councilors") until the first annual meeting of the Society are:

Names	*Post office addresses*
HEINRICH RIES	401 Thurston Avenue, Ithaca, New York.
WILLIAM SHIRLEY BAYLEY	706 South Coler Avenue, Urbana, Illinois.
ULYSSES SHERMAN GRANT	627 Library Place, Evanston, Illinois.
ERMINE COWLES CASE	619 University Avenue, Ann Arbor, Michigan.
ARTHUR LEONARD PARSONS	79 Oriole Road, Toronto, 5, Canada.
CHARLES PETER BERKEY	1076 Cumbermede Road, Palisade, New Jersey.
EDWARD BENNETT MATHEWS	Lombardy Apartment, 40th and Stony Run Lane, Baltimore, Maryland.
JOSEPH STANLEY-BROWN	151 Quentin Street, Kew Gardens, Long Island, New York.
HARRY FOSTER BAIN	38 East 53rd Street, New York, New York.
HENRY BARNARD KUMMEL	917 Edgewood, Trenton, New Jersey.
GEORGE ROGERS MANSFIELD	2067 Park Road, Washington, D. C.
WILLIAM EMBRY WRATHER	4300 Overhill Drive, Dallas, Texas.
HERDMAN FITZGERALD CLELAND	2 Lynde Lane, Williamstown, Mass.
ELWOOD MOORE	16 Indian Grove, Toronto, 3, Canada.
ANDREW COWPER LAWSON	1515 La Loma Avenue, Berkeley, California.
ARTHUR KEITH	2210-20th Street, Washington, D. C.
BAILEY WILLIS	539 Lasuen Street, Stanford University, California.

7. All of the subscribers to this certificate are of full age; at least two-thirds of them are citizens of the United States; at least one of them is a resident of the State of New York; and at least one of the persons named as director is a citizen of the United States and resident of the State of New York.

IN WITNESS WHEREOF, we have made, signed, acknowledged, and filed this certificate in duplicate.

Dated this 28th day of March, 1929.

(Signed) HENRY FAIRFIELD OSBORN,
JOSEPH STANLEY-BROWN,
CHARLES P. BERKEY,
HEINRICH RIES,
H. FOSTER BAIN.

STATE OF NEW YORK,
County of New York, ss:

On this 28th day of March, 1929, before me personally came Charles P. Berkey, H. Foster Bain, Joseph Stanley-Brown and Henry Fairfield Osborn, to me known and known to me to be the four (4) of the five (5) individuals described in and who executed the foregoing instrument and they severally acknowledged to me that they executed the same.

(Signed) JOHN T. BREUNICH,
Notary Public, Westchester County.

New York County Clerk's No. 1134, New York County Register's No. 0-856. Term expires March 30, 1930.

STATE OF NEW YORK,
County of Tompkins, ss:

On this 3rd day of April, 1929, before me personally came Heinrich Ries, to me known and known to me to be one (1) of the five (5) individuals described in and who executed the foregoing instrument and he acknowledged to me that he executed the same.

(Signed) RACHEL K. BOUTON,
Notary Public.

CERTIFICATE OF CHARLES P. BERKEY

STATE OF NEW YORK,
County of New York, ss:

CHARLES P. BERKEY, being duly sworn, deposes and says:

1. That he is one of the subscribers of the Annexed Certificate of Incorporation of The Geological Society of America, Inc., an existing unincorporated society, and he hereby certifies:

2. That he is a citizen of the United States of America and a resident of the State of New Jersey.

3. That The Geological Society of America, an unincorporated society, was organized on December 27, 1888, for the following purpose:

"The Promotion of the Science of Geology in North America."

4. That the purposes set forth in the annexed Certificate of Incorporation are the same as those of the unincorporated society.

5. That the subscribers of the annexed Certificate of Incorporation constitute all the members of a committee authorized to incorporate such society by vote as required by the organic law of the society for the amendment of such organic law.

6. That an annual meeting of the members of said society was held at the American Museum of Natural History in the Borough of Manhattan, city, county, and State of New York, on the 28th day of December, 1928.

7. That a notice of the time and place of such annual meeting and of the intention to submit the question of the proposed incorporation of said society and the appointment of a committee authorized to incorporate such society to said meeting was submitted in print to all of the members of said society more than three months previous to said meeting as required by the organic law of said society for the amendment of such organic law which provides as follows:

ARTICLE V

VOTING AND ELECTIONS

1. "All elections shall be by ballot. To elect a Fellow, Correspondent or Patron, or impose any special tax, shall require the assent of nine-tenths of all Fellows voting."

2. "Voting by letter may be allowed."

ARTICLE IX

AMENDMENTS

1. "This Constitution may be amended at any annual meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting."

8. That at the said meeting it was reported by deponent as Secretary of the Society that written votes in favor of the incorporation of the Society and the appointment of such committee, pursuant to said notice, had been received from more than three-fourths of the members (known as "Fellows"), namely, from four hundred and thirty-nine (439) members out of the total membership of five hundred thirty-six (536).

9. That the said annual meeting thereupon by the unanimous vote of all the members of the society present and voting and by the written votes of four hundred thirty-nine (439) members hereinabove referred to adopted the following resolution:

RESOLUTION OF INCORPORATION OF THE GEOLOGICAL SOCIETY OF AMERICA, RECOMMENDED BY THE COUNCIL

WHEREAS a special Finance Committee was appointed by the President to study the financial structure of the Society and recommended that such steps as may be necessary should be taken to Incorporate the Society; and

WHEREAS the Council pursuant to the provisions of the Constitution of the Society submitted in print to all the Fellows under date of September 28, 1928 (said date being three months previous to the date of this meeting), a proposal to incorporate this Society and stated in said proposal that the Society would be called upon at the annual meeting to elect a committee of at least five to accomplish incorporation, in the event that at least three-quarters of all the Fellows voted in favor of the said proposal to Incorporate the Society; and

WHEREAS votes in favor of the incorporation of the Society have been received from more than three-quarters of all the Fellows, namely, from four hundred and thirty-nine (439) Fellows out of a total of five hundred and thirty-six Fellows; and

WHEREAS it is deemed advisable by the Council that the Society should be incorporated under the provisions of the Membership Corporations Law of the State of New York; and

WHEREAS it is provided in the said law that any unincorporated association, society, league or club not organized for pecuniary profit may be incorporated under the said law, provided that the subscribers of the Certificate of Incorporation constitute a majority of the members of a committee consisting of at least five persons, which committee has been authorized to incorporate such association, society, league or club by vote as required by the organic law of the association, society, league or club, for the amendment of such organic law; and

WHEREAS all the conditions hereinabove set forth contained in the laws of the State of New York as conditions precedent to the incorporation of this Society have been complied with, it is now on motion, duly made and seconded, unanimously *Resolved*, that Charles P. Berkey (Chairman), Heinrich Ries, H. Foster Bain, Joseph Stanley-Brown, and Henry Fairfield Osborn, be and they hereby are authorized to incorporate The Geological Society of America, an existing unincorporated society, not organized for pecuniary profit, pursuant to the provisions of Membership Corporations Law of the State of New York, for the purposes for which it was organized, which said purposes are purposes for which a corporation may be formed under the Membership Corporations Law of the State of New York, and to take any and all such steps as may be provided for by law or may be advisable or necessary to complete the said incorporation, including the execution of the Certificate of Incorporation of the Society and any and all other documents which may be necessary or requisite."

(Signed) CHARLES P. BERKEY.

Sworn to before me this 28th day of March, 1929.

JOHN T. BREUNICH,
Notary Public, Westchester County.

New York County Clerk's No. 1134. New York County Register's No. 0-856. Term expires March 30, 1930.

STATE OF NEW YORK,
County of New York, ss:

JOSEPH STANLEY-BROWN, being duly sworn, deposes and says:

1. That he is one of the incorporators of The Geological Society of America, Inc., an existing unincorporated society, and he hereby testifies: That he is a citizen of the United States of America and a resident of the State of New York.

2. That the purposes set forth in the proposed Certificate of Incorporation of "The Geological Society of America, Inc.," are the same as those of The Geological Society of America, an unincorporated society, organized on December 27, 1888, and

3. That the subscribers of the annexed Certificate of Incorporation constitute all the members of a committee authorized to incorporate such society, by vote as required by the organic law of the Society for the amendment of such organic law.

(Signed) JOSEPH STANLEY-BROWN.

Sworn to before me this 28th day of March, 1929.

JOHN T. BREUNICH,
Notary Public, Westchester County.

New York County Clerk's No. 1134. New York County Register's No. 0-856. Term expires March 30, 1930.

STATE OF NEW YORK,
County of New York, ss:

H. FOSTER BAIN, being duly sworn, deposes and says:

1. That he is one of the incorporators of The Geological Society of America, Inc., an existing unincorporated society, and he hereby testifies: That he is a citizen of the United States of America and a resident of the State of New York.

2. That the purposes set forth in the proposed Certificate of Incorporation of "The Geological Society of America, Inc.," are the same as those of The Geological Society of America, an unincorporated society, organized on December 27, 1888, and

3. That the subscribers of the annexed Certificate of Incorporation constitute all of the members of a committee authorized to incorporate such society, by vote as required by the organic law of the Society for the amendment of such organic law.

(Signed) H. FOSTER BAIN.

Sworn to before me this 28th day of March, 1929.

JOHN T. BREUNICH,
Notary Public, Westchester County.

New York County Clerk's No. 1134. New York County Register's No 0-856. Term expires March 30, 1930.

STATE OF NEW YORK,
County of New York, ss:

HENRY FAIRFIELD OSBORN, being duly sworn, deposes and says:

1. That he is one of the incorporators of The Geological Society of America, Inc., an existing unincorporated society, and he hereby testifies: That he is a citizen of the United States of America and a resident of the State of New York.

2. That the purposes set forth in the proposed Certificate of Incorporation of "The Geological Society of America, Inc.," are the same as those of The Geological Society of America, an unincorporated society, organized on December 27, 1888, and

3. That the subscribers of the annexed Certificate of Incorporation constitute all of the members of a committee authorized to incorporate such society, by vote as required by the organic law of the Society for the amendment of such organic law.

(Signed) HENRY FAIRFIELD OSBORN.

Sworn to before me this 28th day of March, 1929.

JOHN T. BREUNICH,
Notary Public, Westchester County.

New York County Clerk's No. 1134. New York County Register's No. 0-856. Term expires March 30, 1930.

STATE OF NEW YORK,
County of Tompkins, ss:

HEINRICH RIES, being duly sworn, deposes and says:

1. That he is one of the incorporators of The Geological Society of America,

Inc., an existing unincorporated society, and he hereby testifies: That he is a citizen of the United States of America and a resident of the State of New York.

2. That the purposes set forth in the proposed Certificate of Incorporation of "The Geological Society of America, Inc.," are the same as those of The Geological Society of America, an unincorporated society, organized on December 27, 1888, and

3. That the subscribers of the annexed Certificate of Incorporation constitute all of the members of a committee authorized to incorporate such society, by vote as required by the organic law of the Society for the amendment of such organic law.

(Signed) HEINRICH RIES.

Sworn to before me this 3rd day of April, 1929.
RACHEL K. BOUTON,
Notary Public.

STATE OF NEW YORK,
County of New York, ss:

WILLIAM CAMPBELL ARMSTRONG, being duly sworn, deposes and says that he is attorney for Charles P. Berkey, Joseph Stanley-Brown, Henry Fairfield Osborn, H. Foster Bain and Heinrich Ries, who have signed the foregoing Certificate of Incorporation; that, to the best of his knowledge and belief, no previous application for incorporation of "The Geological Society of America, Inc., has heretofore been made by said incorporators or any of them.

(Signed) WILLIAM CAMPBELL ARMSTRONG.

Sworn to before me this 8th day of April, 1929.
WALTER W. COX,
Notary Public, New York County.

New York County Clerk's No. 232; New York County Register's No. 0-86. Commission expires March 30, 1930.

CERTIFICATE OF CORRECTNESS

STATE OF NEW YORK,
Department of State, ss:

I certify that I have compared the preceding copy with the original Certificate of Incorporation of

"The Geological Society of America, Inc.,"

filed in this department on the 3rd day of May, 1929, and that such copy is a correct transcript therefrom and of the whole of such original.

Witness my hand and the official seal of the Department of State at the City of Albany, this third day of May, one thousand nine hundred and twenty-nine.

(Signed) FRANK S. SHAYS,
Deputy Secretary of State.

BY-LAWS

ARTICLE I

NAME AND SEAL

1. This Society shall be known as THE GEOLOGICAL SOCIETY OF AMERICA, INCORPORATED.

2. The corporate seal of the Society shall be circular in form and shall bear the name of the Society and the year of its incorporation. It may also bear any device approved by the Council of the Society.

ARTICLE II

MEMBERSHIP AND ELECTION OF MEMBERS

The Society shall be composed of Fellows, Correspondents, and Patrons.

1. Fellows shall be persons who are engaged in geological work or in teaching geology.

Fellows admitted without election under the provisional Constitution shall be designated as Original Fellows on all lists or catalogues of the Society.

2. Correspondents shall be persons distinguished for their attainments in geological science and not resident in North America.

3. Patrons shall be persons who have bestowed important favors on the Society.

4. Fellows alone shall be entitled to vote or hold office in the Society.

5. No person shall be accepted as a Fellow unless he pays his initiation fee, and the dues for the year, within three months after notification of his election. The initiation fee shall be ten (10) dollars and the annual dues ten (10) dollars, the latter payable on or before the annual meeting; but a single prepayment of one hundred fifty (150) dollars shall be accepted as commutation for life. A Fellow in good standing, however, who has paid annual dues for not less than fifteen (15) years may commute further dues and become a Life Fellow by making a single payment of one hundred (100) dollars.

6. The sums paid in commutation of dues shall be covered into the Publication Fund.

7. An arrearage in payment of annual dues shall deprive a Fellow of the privilege of taking part in the management of the Society and of receiving its publications. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

8. Any person eligible under section 3 of this article may be elected Patron on the payment of one thousand (1,000) dollars to the Publication Fund of the Society.

9. All elections shall be by ballot. To elect a Fellow, Correspondent or Patron, or impose any special tax, shall require the assent of nine-tenths of all Fellows voting.

10. Voting by letter may be allowed.

11. Nominations for fellowship may be made at any time by two Fellows on blanks to be supplied by the Secretary. One of these Fellows must be personally acquainted with the nominee and his qualifications for membership.

12. The form for the nomination of Fellows shall be as follows:

In accordance with his desire, we respectfully nominate for Fellow of the Geological Society of America:

Full name; degrees, address, occupation, branch of geology now engaged in, work already done and publications made.

(Signed by at least two Fellows.)

The form when filled is to be transmitted to the Secretary.

13. The Secretary will bring all nominations before the Council, and the Council will signify its approval or disapproval of each.

14. At least a month before the annual meeting of the Society the Secretary shall mail to each Fellow a suitable form of ballot, and return envelopes, including a printed list of all approved nominees, accompanied by such information as may be necessary for intelligent voting.

15. The Fellows receiving the list will signify their approval or disapproval of each nominee, and return the lists to the Secretary.

16. At the next stated meeting of the Council the Secretary will present the lists and the Council will canvass the returns.

17. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for fellowship.

18. At the next stated meeting of the Society the Council shall declare the results, after which notice shall be sent to Fellows elect.

19. Correspondents and Patrons shall be nominated by the Council, and shall be elected in the same manner as Fellows.

Article III

Officers and their duties

1. *Council.* The officers of the Society shall consist of a President, a First Vice-President, a Second Vice-President, and one Vice-President to represent each of the societies affiliated with this Society, a Secretary, a Treasurer, an Editor, six other Councilors, and one Representative for each of the authorized Sections of the Society.

These officers, together with the Presidents for the next preceding three years, shall constitute the Board of Directors, which shall be called the Council.

2. *Duties.* The President shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Articles of Incorporation and By-Laws to be carried faithfully into effect. He shall countersign, if he approves, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

3. The First Vice-President shall assume the duties of President in case of the absence or disability of the latter. The Second Vice-President shall assume the duties of President in case of the absence or disability of both the President and First Vice-President. A Vice-President or other officer to be named by the Council shall assume the duties of President in case of the absence or disability of the President and First and Second Vice-Presidents.

4. The Secretary shall keep the records of the proceedings of the Society, and a complete list of the Fellows, with the dates of their election and disconnection with the Society. He shall also be the secretary of the Council.

The Secretary shall cooperate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing and mailing of circulars, blanks and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution, under the direction of the Council. He shall submit an annual report to the Council, and unless other provision be made, shall act as Custodian of all property, except that in the custody of the Treasurer. The Society may elect an Assistant Secretary.

5. The Treasurer shall have the custody of all funds of the Society. He shall keep an account of receipts and disbursements in detail, and this shall be audited as hereinafter provided. He shall give bond, approved by the Council, in the sum of five thousand dollars or such larger amount as the Council may direct, for the faithful and honest performance of his duties and the safekeeping of the funds and securities of the Society. He shall deposit the funds of the Society in a bank of recognized standing and shall keep its securities in the Society's box in the vaults of a reliable bank, safe deposit or trust company. All funds in excess of the Society's current requirements shall be invested as provided for in paragraph 7 of this Article. His accounts shall be balanced as on the thirtieth day of November of each year. He shall submit an annual report to the Council of all receipts and disbursements and include therein a list of the Society's investments.

6. The Editor shall supervise all matters connected with the publication of the transactions of the Society under the direction of the Council.

7. The Council is clothed with executive authority and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. It shall receive nominations for Fellows, and, on approval, shall submit them to the Society for action. It shall have power to fill vacancies *ad interim* in any of the offices of the Society. The minutes of its proceedings shall be subject to call by the Society.

It may transact its business by correspondence during the intervals between its stated meetings; but affirmative action by a majority of the Council shall be necessary in any order to make action by correspondence valid.

Each year at the annual meeting of the Society, the President shall, with the approval of the Council, appoint a Finance Committee, consisting of three members of the Council, to serve for one year. The Treasurer also shall be, *ex-officio*, a member of this committee. Any member shall be eligible for reappointment on this committee.

When the Treasurer finds that there are funds available for investment he shall notify the Finance Committee and this committee shall recommend suitable investments to the Council for final action at its next meeting.

In addition to the foregoing specific duties the Finance Committee shall act as the general financial advisory body of the Society.

The Finance Committee shall be at all times under the direction of the Council and nothing contained in this amendment shall be construed as modifying in any way the authority of the Council to take at any time any action which it may deem necessary to safeguard the financial interests of the Society.

At each annual meeting the Council shall submit to the Society a report which shall include the report of the Secretary, of the Treasurer, and of such other officers or committees, and such other information as the Council may direct. There shall also be submitted to the members present for appropriate action a resolution providing for the ratification and confirmation of all acts of the Council for the preceding year.

ARTICLE IV

ELECTIONS OF OFFICERS AND TERMS OF OFFICE

1. *Elections.*—The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket. The ticket must be approved by a majority of the entire Council. The nominee for President shall not be a member of the Council. The nominee for the Vice-President representing an affiliated society shall be from the joint fellowship by vote of the affiliated society concerned, subject to confirmation by the Council of the Geological Society of America. The nominee for Third Vice-President shall be the nominee for the presidency of the Paleontological Society, and the nominee for the Fourth Vice-President shall be the nominee for the presidency of the Mineralogical Society of America. In the selection of the six other Councilors the various sections of North America shall be represented as far as practicable.

2. The list shall be mailed to the Fellows, for their information, at least eight months before the Annual Meeting. Any five Fellows may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least 40 days before the Annual Meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows at least 25 days before the Annual Meeting.

3. The Fellows will send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the Annual Meeting of the Council, the Secretary will bring the returns of ballots before the Council for canvass, and during the Annual Meeting of the Society the Council shall declare the result. The officers thus elected shall enter on duty at the adjournment of the meeting.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such Annual Meeting proceed to make an election for such office from the two candidates having the highest number of votes.

Terms of Office. 5. The President and Vice-Presidents shall be elected annually, and shall not be eligible for re-election until after an interval of three years from date of retirement.

6. The Secretary, Treasurer, and Editor shall be eligible for re-election without limitation.

7. The terms of office of the six Councilors shall be three years; and these officers shall be so grouped that two shall be elected and two retire each year. Councilors retired shall not be re-eligible for election until after the expiration of a year.

8. The term of office of the Representative of a Section of the Society shall be three years, and he shall not be eligible for re-election until after the expiration of a year.

Article V

Meeting and Order of Business

1. The Society shall hold at least one stated meeting a year, in the winter season, which shall be the *Annual Meeting*. The date and place shall be fixed by the Council, and announced each year within four months after the adjournment of the preceding Annual Meeting. The program of each meeting shall be determined by the Council, and announced beforehand, in its general features. The details of the daily sessions shall be arranged also by the Council.

2. Special meetings may be called by the Council, and must be called on the written request of twenty Fellows.

3. Meetings of the Council shall be held coincidently with the meetings of the Society. Special meetings may be called by the President at such times as he may deem necessary.

4. *Quorum.*—At meetings of the Society twenty-five Fellows shall constitute a quorum. Five shall constitute a quorum of the Council.

5. The Order of Business at Annual Meetings shall be as follows:

(1) Call to order by the presiding officer.
(2) Introductory ceremonies.
(3) Report of the Council (including report of the officers).
(4) Appointment of the Auditing Committee.
(5) Declaration of the vote for officers, and election by the meeting in case of failure to elect by the Society through transmitted ballots.
(6) Declaration of the vote for Fellows.
(7) Deferred business.
(8) New business.
(9) Announcements.
(10) Necrology.
(11) Reading of scientific papers.

6. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.

7. At any Special Meeting the order of business shall be numbers (1), (2), and (9), followed by the special business for which the meeting was called.

Article VI

FINANCIAL METHODS

1. No pecuniary obligation shall be contracted without expressed sanction of the Society or the Council, but all ordinary, incidental, and running expenses shall have the permanent sanction of the Society, without special action.

2. A creditor of the Society must present to the Treasurer a fully itemized bill, certified by the official ordering it, and approved by the President. The Treasurer shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

3. At each annual meeting, the President shall call on the Society to choose two Fellows, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as specified in the By-Laws, Article III, clause 5. The Auditors shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action thereon.

4. Within thirty days after the Annual Meeting at least one of the Auditors shall verify the securities in custody of the Treasurer and report his findings to the President, which report shall be published in the Bulletin.

Article VII

PUBLICATIONS AND PUBLICATION FUND

1. The publications shall be in charge of the Council and under its control.

2. One copy of each publication shall be sent to each Fellow, Correspondent, and Patron, and each author shall receive forty (40) copies of his memoir.

3. The Publication Fund shall consist of donations made in aid of publication, the sums paid in commutation of dues, and such other amounts as may be allocated by the Council for this purpose.

4. Donors to this fund, not Fellows of the Society, in the sum of two hundred dollars, shall be entitled, without charge, to the publications subsequently appearing.

Article VIII

SECTIONS

1. Any group of Fellows representing a particular branch of geology or definite region may, with consent of the Council, organize as a Section of the Society with separate constitution and by-laws, provided that nothing in such constitution and by-laws conflicts with the Articles of Incorporation and By-Laws of the Geological Society of America, Inc., in spirit, and provided that such constitution and by-laws and all amendments thereto have been approved by the Council.

2. Fellows of the Society residing west of the 105th Meridian are authorized to organize as a section of the Society, to be known as the Cordilleran Section. The purpose of the Cordilleran Section shall be to serve the con-

venience of Fellows of the Society in the matter of arranging and holding meetings for the discussion of scientific questions in the region of its membership. It shall operate under the By-Laws of the Society, but may adopt by-laws governing its conduct which are not inconsistent with the Articles of Incorporation and By-Laws of the Society. It is authorized to nominate a representative to the Council of the Society who shall be designated Representative of the Cordilleran Section. The Representative of the Cordilleran Section shall hold office for three years and shall have a vote on all matters coming before the Council for decision.

ARTICLE IX

AMENDMENTS

1. Subject to the approval of the proper authority of the State of New York, the Articles of Incorporation may be amended by a three-fourths vote by ballot of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows.

2. By-Laws may be made or amended by a majority vote by ballot provided that printed notice of the proposed amendment or by-law shall have been sent to all Fellows:

Approved by the Council October 26, 1929.

Publication Rules of The Geological Society of America

(Adopted by the Council April 21, 1891; Revised April 30, 1894, May, 1904, February 5, 1910 and October 11, 1930)

General Provisions

Section 1. The Publication Committee shall consist of the Secretary, the Treasurer, the Editor, and two other members of the Society to be appointed annually by the Council. The duties of the Committee shall be to determine the disposition of matter offered for publication, except as provided in section 12; to determine the expediency, in view of the financial condition of the Society, of publishing any matter accepted on its merits; to exercise general oversight of the matter and manner of publication; to determine the share of the cost of publication (including illustrations) to be borne by the author when it becomes necessary to divide cost between the Society and the author; to adjudicate any questions relating to publication which may be raised from time to time by the Editor or by the Fellows of the Society; and in general to act for the Council in all matters pertaining to publication. (By-Laws, Article VII, Paragraph 1.)

2. The duties of the Editor are to receive from the Secretary of the Society material offered for publication; to publish all material accepted by the Council or Publication Committee; to revise proofs in connection with authors; to prepare an index for each volume; to audit bills for printing and illustrating; and to perform all other duties connected with publication not assigned to other officers. Each author shall receive galley proofs and proofs of his illustrations, but the Editor shall not be required to send page proof except in such cases as, in his judgment, he may deem it desirable to do so.

3. The duties of the Secretary include the preparation of a record of the proceedings of each meeting of the Society in form for publication and the assembling, and forwarding to the Editor all papers which are to be published. The Secretary also shall have charge of the censoring of manuscripts, and if he deems it desirable he may submit a manuscript to a professional reader and then forward the revised copy to the author for final acceptance or rejection. In determining the relevancy, the scientific and literary value of a paper and on the selection of a censor or censors the Secretary shall, when he deems it desirable, confer with the Publication Committee. The custody, distribution, sale, exchange or other authorized disposition of the publications shall be in charge of the Secretary.

4. Special committees may be appointed by the Council or the Publication Committee to examine and report on any matter offered for publication.

The Bulletin

TITLE AND GENERAL CHARACTER

5. The Society shall publish a serial record of its work entitled "Bulletin of the Geological Society of America."

6. The Bulletin shall be published in quarterly parts, consecutively paged for each volume. The parts shall be suitably designated and each part shall bear on the cover the title Bulletin of the Geological Society of America, the seal of the Society and the date of publication. The inside of the first leaf of the cover shall carry a table of contents setting forth the list of papers, and their authors contained in the part, and on the inside of the last leaf of the cover shall appear the names of the officers, Councilors and Representatives of the Society and the members of the Publication Committee.

7. The closing quarterly part of each volume shall contain an index, paged consecutively with the body of the volume; and it shall be accompanied by a volume title-page and lists of contents and illustrations, together with lists of the publications of the Society and such other matter as the Publication Committee may deem necessary, all arranged under Roman pagination.

MATTER OF THE BULLETIN

8. The matter published in the Bulletin shall comprise (1) communications read at meetings, presented by title or otherwise; (2) communications or memoirs not presented before the Society; (3) abstracts of papers read before the Society, prepared or revised for publication by authors; (4) reports of discussions held before the Society, prepared or revised for publication by authors; (5) proceedings of the meetings of the Society prepared by the Secretary; (6) plates, maps, and other illustrations necessary for the proper understanding of communications; (7) lists of Officers and Fellows, Articles of Incorporation, By-Laws, Publication Rules, resolutions of permanent character, rules relating to procedure, and to other matters, and (8) indexes, title-pages, and lists of contents for each volume.

9. Abstracts, reports of discussion, or other matter purporting to emanate from any author shall not be published unless prepared or revised by the author.

10. Manuscript designed for publication in the Bulletin must be complete as to copy for text and illustration, except by special arrangement between the author and the Council or Publication Committee; it must be perfectly legible (preferably typewritten); it must be preceded by a table of contents and, as far as possible, conform to the arrangement set forth in the sample guide distributed to authors by the Secretary. The cost of necessary revision of copy or reconstruction of illustrations shall be assessed on the author.

11. The Editor shall examine and arrange matter placed in his hands for publication, and shall use due diligence in passing it through the press. Questions of disagreement between the Editor and authors shall be referred to the Publication Committee and appeal may be taken to the Council.

12. Communications from non-fellows shall be published only by specific authority from the Publication Committee, which if it so desires may ask for a decision by the Council.

13. Communications from Fellows not presented at regular meetings of the Society shall be published only on unanimous vote of the Publication Committee, unless specifically authorized by the Council.

14. Matter offered for publication becomes thereby the property of the Society, and shall not be published elsewhere prior to publication in the Bulletin, except by consent of the Publication Committee.

DETAILS OF THE BULLETIN

15. The matter of each memoir shall be classified by subjects, and the classification suitably indicated by subtitles; and a table of contents shall be arranged by the author and placed at the head of the paper. The author must distribute through the manuscript the titles and subtitles appearing in the contents and also insert in the "copy" at the place where the cut is to appear the number and title of the figure.

16. Proofs of text and illustrations shall be submitted to authors whenever practicable; and complete proofs of the proceedings of meetings shall be sent to the several Secretaries, but printing shall not be delayed by reason of absence or incapacity of authors more than one week beyond the time required for transmission by mail.

17. The cost of proof corrections in excess of ten per cent on the cost of printing may be charged to authors.

18. The discussions on communications shall be printed at the end of papers, with a suitable reference in the list of contents.

19. The author of each memoir occupying four pages or more of text in the body of the Bulletin shall receive 40 "separates" without charge, and may order through the Secretary any edition of exactly similar separates at an advance of ten per cent on the cost of paper, presswork and binding; and no author's separates of such memoirs shall be issued except in this regular form.

20. Authors of papers, abstracts, or discussions less than four printed pages in length may order, through the Secretary, at an advance of ten per cent on the cost of paper, presswork, binding and necessary composition, any number of extra copies, provided they bear the original pagination and a printed reference to the serial and volume from which they are extracted.

21. The Editor shall keep a record of all publications issued wholly or in part under the auspices of the Society, whether they be author's editions of memoirs, author's extracts from proceedings, or any other matter printed from type originally composed for the Bulletin, and this record shall appear at an appropriate place in the "preliminary matter."

DIRECTIONS TO PRINTER

22. Each memoir of the Bulletin shall begin, under its proper title, on an odd-numbered page bearing at its head the title of the serial, the volume number, the part number, the limiting pages, the plates, the number of figures and the date of publication, together with a table of contents. Each memoir shall

be accompanied by the illustrations pertaining to it, the plates numbered consecutively for the volume and the figures numbered consecutively only for the individual paper.

23. The author's separates of each memoir shall be enclosed in a cover bearing at the head of its title-page the title of the serial, the volume number, the limiting pages, and the numbers of the contained plates; in its upper-central part a title indicating the contents and authorship; in its lower-central part the seal of the Society; and at the bottom the imprint of the Society. (See also sections 19 and 20.)

24. The bottom of each signature and each initial page will bear a signature mark giving an abbreviated title of the serial, the volume, and the year; and every page (except volume title-page) shall be numbered, the initial and subtitle pages in parentheses at bottom.

25. The page-head titles shall be: on even-numbered pages, name of author and catch title of paper; on odd-numbered pages, catch title to contents of page.

26. The date of publication of each brochure shall be the day upon which the last form is locked and put on the press.

27. The type used in printing the Bulletin shall be as follows: For memoirs, body, long primer, 6-to-pica leads; extracts, brevier, 8-to-pica leads; footnotes, nonpareil, set solid; titles, long primer caps, with small caps for author's name; subtitles, long primer caps, small caps, italic, etcetera, as far as practicable; for designation of cuts, nonpareil caps and italics, and for legends, nonpareil, Roman, set solid; for lists of contents of brochures, brevier, 6-to-pica leads, a new line to an entry, running indentation; for volumes, the same, except 4-to-pica leads and names of authors in small caps; for indexes, nonpareil, set solid, double column, leaders, catch words in small caps, with spaces between initial letters. For serial titles, on initial pages, brevier block caps, with corresponding small caps for volume designation, etcetera; on covers, the same, except for page heads long primer caps; for serial designation, long primer; for brochure designation, pica caps; special title and author's name, etcetera, long primer and brevier caps; no frame on cover. No change in type shall be made to adjust matter to pages.

28. Volumes, plates, and cuts in text shall be numbered in Arabic; Roman numeration shall be used only in signature marks, and in paging the lists of contents and other preliminary matter, arranged for binding at the beginning of the volume.

29. Imprimatur of Editor, on volume title-page, imprimatur of Council and Publication Committee, on obverse of volume title-page; imprimatur of Secretary, on initial pages and covers of brochures of proceedings. Printer's and Engraver's cards in fine type on obverse of title-page.

30. The paper shall be for body of volume, 70-pound toned paper, folding to 16 x 25 centimeters; for plates, good quality, plate paper, smooth-surfaced, white, cut to 6½ x 10 inches for single plates; for covers smooth-surfaced, fine quality 70-pound light-buff manila paper.

31. The sheets of the brochures shall be stitched with thread; single page plates shall be stitched with the sheets of the brochures; folding plates may be

either gummed or stitched (mounted on stubs if necessary); covers shall be gummed.

EDITION, DISTRIBUTION, AND PRICE

32. The regular edition shall be 1,200 copies in the regular quarterly form and 65 copies separately in covers of each memoir occupying four pages or more of text, but additional separates, varying in amounts, may be ordered by the Society, by members or affiliated societies. Each author of a memoir occupying not less than four pages of text shall receive 40 copies of his memoir gratis. If two or more authors contribute to a memoir brochure of four pages or more in length, the edition shall be enlarged so as to give each author 40 copies. (By-Laws, Article VII, Paragraph 2.)

33. The undistributed residue of separates shall be held for sale.

34. The Bulletin shall be sent free to Fellows of the Society not in arrears for dues, and to each Correspondent and Patron, and also to exchanging institutions. (By-Laws, Article VII, Paragraph 2.)

35. The price of the Bulletin shall be as follows: To Fellows, libraries, and institutions, and to individuals not residing in North America, $9.00 per volume; to individuals residing in North America and who are not Fellows, $10. The price of each brochure shall be a multiple of five cents, and shall be, to Fellows, one cent per page plus three cents per plate, and to the public an advance of fifty per cent on the price to Fellows. The prices of the separate brochures and of the quarterly parts will be found in the front of each volume.

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1931

President:

ALFRED C. LANE, Boston, Mass.

Vice-Presidents:

THOMAS L. WALKER, Toronto, Canada.
HENRY B. KUMMEL, Trenton, N. J.
EDGAR R. CUMINGS, Bloomington, Ind.
ALEXANDER H. PHILLIPS, Princeton, N. J.

Secretary:

CHARLES P. BERKEY, Columbia University, New York, N. Y.

Treasurer:

EDWARD B. MATHEWS, Baltimore, Md.

Editor:

JOSEPH STANLEY-BROWN, 151 Quentin St., Kew Gardens, L. I.

Councilors:

(Term expires 1931)
HERDMAN F. CLELAND, Williamstown, Mass.
ELWOOD S. MOORE, Toronto, Canada.

(Term expires 1932)
W. C. MENDENHALL, Washington, D. C.
W. J. MEAD, Madison, Wis.

(Term expires 1933)
SIDNEY POWERS, Tulsa, Okla.
DONNEL F. HEWETT, Washington, D. C.

Representative of the Cordilleran Section:

ELIOT BLACKWELDER, Stanford University, Calif.

MEMBERSHIP, 1931

CORRESPONDENTS

BARROIS, CHARLES, Lille, France. Dec., 1909.
BATHER, FRANCIS ARTHUR, London, England. Dec., 1926.
BRÖGGER, W. C., Oslo, Norway. Dec., 1909.
DAVID, SIR TANNATT WILLIAM EDGEWORTH, Sydney, New South Wales. Dec., 1923.

De Geer, Baron Gerhard, Stockholm, Sweden. Dec., 1910.
De Margerie, Emmanuel, Strasbourg, Alsace, France. Dec., 1921.
Flett, Sir John Smith, London, England. Dec., 1928.
Gregory, John Walter, Glasgow, Scotland, Dec., 1930.
Harker, Alfred, Cambridge, England. Dec., 1924.
Heim, Albert, Zurich, Switzerland. Dec., 1909.
Kiaer, Johan, Oslo, Norway. Dec., 1925.
Koto, Bunjiro, Tokyo, Japan. Dec., 1923.
Lacroix, François Antoine Alfred, Paris, France. Dec., 1923.
Loewinson-Lessing, Franz J., Leningrad, U. S. S. R. Dec., 1926.
Molengraaff, Gustaaf Adolf Frederik, Delft, Holland. Dec., 1923.
Obruchev, Vladimir A., Leningrad, U. S. S. R. Dec., 1930.
Penck, Albrecht, Berlin, Germany. Dec., 1930.
Rogers, Arthur William, Cape Town, South Africa. Dec., 1924.
Sollas, William Johnson, Oxford, England. Dec., 1925.
Sederholm, Jakob Johannes, Helsingfors, Finland. Dec., 1923.
Stille, Hans W., Göttingen, Germany. Dec., 1930.
Termier, Pierre M., Paris, France. Dec., 1928.
Vogt, J. H. L., Oslo, Norway. Dec., 1925.
Walther, Johannes, Halle-Wittenberg, Germany. Dec., 1926.
Watts, William Whitehead, London, England. Dec., 1930.
Woodward, Sir Arthur Smith, London, England. Dec., 1923.

FELLOWS

* Indicates Original Fellows (see article II of By-laws)

Abbe, Cleveland, Jr., 123 North Quarry St., Ithaca, N. Y. August, 1899.
Adams, Frank Dawson, McGill University, Montreal, Canada. Dec., 1889.
Adams, George I., University of Alabama, Tuscaloosa, Ala. Dec., 1902.
Adams, Leason H., Geophysical Laboratory, Washington, D. C. Dec. 1922.
Adkins, Walter S., University of Texas, Austin Texas. Dec., 1921.
Agar, William M., Columbia University, New York, N. Y. Dec., 1929.
Alcock, F. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
Alden, William C., U. S. Geological Survey, Washington, D. C. Dec., 1909.
Aldrich, Henry R., State Geological and Natural History Survey, Madison, Wis. Dec., 1927.
Aldrich, Truman H., 1026 Glen Iris Ave., Birmingham, Ala. May, 1889.
Allan, John A., University of Alberta, Edmonton, Alberta, Canada. Dec., 1914.
Allen, Eugene T., Geophysical Laboratory, Washington, D. C. Dec., 1922.
Allen, R. C., 1202 Hanna Bldg., Cleveland, Ohio. Dec., 1911.
Alling, H. L., University of Rochester, Rochester, N. Y. Dec., 1920.
Allison, Ira S., Oregon State College, Corvallis, Ore. Dec., 1929.
Anderson, Frank M., 58 Hillcrest Road, Berkeley, Calif. Dec., 1902.
Anderson, Robert V., Menlo Park, Calif. Dec., 1911.
Andrews, E. C., Geological Survey of New South Wales, Sydney, New South Wales. Dec., 1920.

ANTEVS, ERNST V., American Geographical Society, Broadway at 156th St., New York, N. Y. Dec., 1925.

ARNOLD, RALPH, 812 Subway Terminal Bldg., Los Angeles, Calif. Dec., 1904.

ASHLEY, GEORGE HALL, State Capitol, Harrisburg, Pa. August, 1895.

ATWOOD, WALLACE WALTER, Clark University, Worcester, Mass. Dec., 1909.

AURIN, FRITZ L., Marland Oil Co., Ponca City, Okla. Dec., 1925.

BAGG, RUFUS MATHER, JR., 7 Brokaw Place, Appleton, Wis. Dec., 1896.

BAIN, H. FOSTER, % Amer. Inst. Mining Engineers, 29 W. 39th St., New York, N. Y. Dec., 1895.

BAKER, ARTHUR A., U. S. Geological Survey, Washington, D. C. Dec., 1930.

BAKER, CHARLES L., 529 Commercial Bank Bldg., Houston, Texas. Dec., 1929.

BAKER, MANLEY BENSON, School of Mining, Kingston, Ontario. Dec., 1911.

BALDWIN, S. PRENTISS, 11025 East Blvd., Cleveland, Ohio. August, 1895.

BALL, MAX WAITE, 1104 First Natl. Bank Bldg., Denver, Colo. Dec., 1924.

BALL, SYDNEY H., 26 Beaver St., New York City. Dec., 1905.

BANCROFT, JOSEPH A., McGill University, Montreal, Canada. Dec., 1914.

BARBOUR, ERWIN HINCKLEY, University of Nebraska, Lincoln, Neb. Dec., 1896.

BARBOUR, GEORGE B., Yenching University, Peiping, China. Dec., 1930.

BARRETT, LESLIE PARK, % Inter-State Iron Co., Jones & Laughlin Bldg., Pittsburgh, Pa. Dec., 1923.

BARTON, DONALD C., Petroleum Bldg., Houston, Texas. Dec., 1921.

BARTON, GEORGE H., Boston Soc. of Nat. History, Boston, Mass. Aug., 1890.

BARTRAM, JOHN G., 2555 Clermont St., Denver, Colo. Dec., 1930.

BARTRUM, JOHN ARTHUR, University College, Auckland, N. Z. Dec., 1929.

BARTSCH, PAUL, U. S. National Museum, Washington, D. C. Dec., 1917.

BASCOM, FLORENCE, U. S. Geological Survey, Washington, D. C. August, 1894.

BASSLER, RAY SMITH, U. S. National Museum, Washington, D. C. Dec., 1906.

BASTIN, EDSON S., University of Chicago, Chicago, Ill. Dec., 1909.

BATEMAN, ALAN MARA, Yale University, New Haven, Conn. Dec., 1916.

BAUER, CLYDE MAX, Route 3, Box 61, Boulder, Colo. Dec., 1923.

BAYLEY, WILLIAM S., University of Illinois, Urbana, Ill. Dec., 1888.

BEAN, ERNEST F., Wisconsin Geological and Natural History Survey, Madison, Wis. Dec., 1926.

BEEDE, JOSHUA W., Indiana University, Bloomington, Ind. Dec., 1902.

BEEKLY, ALBERT L., 1106 Cosden Bldg., Tulsa, Okla. Dec., 1925.

BEHRE, CHARLES H., JR., Northwestern University, Evanston, Ill. Dec., 1929.

BELL, WALTER A., Victoria Memorial Museum, Ottawa, Canada. Dec., 1923.

BENSON, W. N., University of Otago, Dunedin, New Zealand. Dec., 1919.

BERKEY, CHARLES P., Columbia University, New York, N. Y. August, 1901.

BERRY, EDWARD WILBER, Johns Hopkins University, Baltimore, Md. Dec., 1909.

BERRY, WILLARD, Ohio State University, Columbus, Ohio. Dec., 1930.

BEVAN, ARTHUR C., Virginia Geological Survey, University, Va. Dec., 1926.

BEYER, SAMUEL WALKER, Iowa Agricultural College, Ames, Iowa. Dec., 1896.

BILLINGS, MARLAND P., Harvard University, Cambridge, Mass. Dec., 1929.

BILLINGSLEY, PAUL, 1027 Continental Natl. Bank Bldg., Salt Lake City, Utah. Dec., 1922.

BLACKWELDER, ELIOT, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1908.

BOUTWELL, JOHN M., Continental National Bank, Salt Lake City, Utah. Dec., 1905.

BOWEN, CHARLES F., % Standard Oil Co., 26 Broadway, New York City. Dec., 1916.

BOWEN, N. L., Geophysical Laboratory, Washington, D. C. Dec., 1917.

BOWIE, WILLIAM, U. S. Coast and Geodetic Survey, Washington, D. C. Dec., 1919.

BOWMAN, ISAIAH, American Geographical Society, Broadway at 156th St., New York City. Dec., 1924.

BRADLEY, WILMOT H., U. S. Geological Survey, Washington, D. C. Dec., 1927.

BRANSON, EDWIN BAYER, University of Missouri, Columbia, Mo. Dec., 1911.

BRETZ, J HARLEN, University of Chicago, Chicago, Ill. Dec., 1917.

BRIGHAM, ALBERT PERRY, Colgate University, Hamilton, N. Y. Dec., 1893.

BROCK, REGINALD W., Univ. of British Columbia, Vancouver, B. C. Dec., 1904.

BRODERICK, T. MONTEITH, Calumet and Hecla Mining Co., Calumet, Mich. Dec., 1921.

BROKAW, A. D., P. O. Box 163, Short Hills, N. J. Dec., 1920.

BROWN, BARNUM, American Museum of Natural History, New York, N. Y. Dec., 1910.

BROWN, CHARLES WILSON, Brown University, Providence, R. I. Dec., 1908.

BROWN, JOHN STAFFORD, Expl. Dept., St. Joseph Lead Co., Edwards, N. Y. Dec., 1922.

BROWN, THOMAS CLACHAR, Laurel Bank Farm, Fitchburg, Mass. Dec., 1915.

BRUCE, E. L., Queen's University, Kingston, Ontario. Dec., 1920.

BRYAN, KIRK, Geological Museum, Oxford St., Cambridge, Mass. Dec., 1922.

BUCHER, W. H., University of Cincinnati, Cincinnati, Ohio. Dec., 1920.

BUDDINGTON, A. F., Prospect Ave., Princeton, N. J. Dec., 1919.

BUEHLER, HENRY ANDREW, Rolla, Mo. Dec., 1909.

BURCHARD, E. F., U. S. Geological Survey, Washington, D. C. Dec., 1920.

BURLING, LANCASTER D., Phillips Petroleum Co., Bartlesville, Okla. Dec., 1917.

BURT, FREDERICK A., Agricultural and Mechanical College, College Station, Texas. Dec., 1929.

BURWASH, EDWARD M. J., Dept. Mines, Parliament Bldgs., Toronto, Canada. Dec., 1916.

BUTLER, BERT S., U. S. Geological Survey, Golden, Colo. Dec., 1912.

BUTLER, G. MONTAGUE, College of Mines, Tucson, Arizona. Dec., 1911.

BUTTS, CHARLES, U. S. Geological Survey, Washington, D. C. Dec., 1912.

BUWALDA, J. P., Institute of Technology, Pasadena, Calif. Dec., 1920.

BYBEE, HALBERT P., Dixie Oil Co., San Angelo, Texas. Dec., 1926.

CADY, G. H., Illinois Geological Survey, Urbana, Ill. Dec., 1920.

CALHOUN, FRED HARVEY HALL, Clemson College, S. C. Dec., 1909.

CALKINS, FRANK C., U. S. Geological Survey, Washington, D. C. Dec., 1914.

CAMPBELL, HENRY D., Washington and Lee Univ., Lexington, Va. May, 1889.

CAMPBELL, MARIUS R., U. S. Geological Survey, Washington, D. C. Aug., 1892.

CAMSELL, CHARLES, Department of Mines, Ottawa, Canada. Dec., 1914.

CAPPS, STEPHEN R., JR., U. S. Geological Surv., Washington, D. C. Dec., 1911.

CARMAN, J. ERNEST, Ohio State University, Columbus, Ohio. Dec., 1917.

CARNEY, FRANK, B. U. Station Box 397, Waco, Texas. Dec., 1908.

CASE, ERMINE C., University of Michigan, Ann Arbor, Mich. Dec., 1901.
CHADWICK, GEORGE H., 175 Bridge St., Catskill, N. Y. Dec., 1911.
CHAMBERLIN, ROLLIN T., University of Chicago, Chicago, Ill. Dec., 1913.
CHANEY, RALPH W., Carnegie Institution of Washington, Berkeley, Calif. Dec., 1926.
CHENEY, MONROE G., Anzac Oil Corporation, Coleman, Texas. Dec., 1930.
CLAPP, CHARLES H., State University, Missoula, Mont. Dec., 1914.
CLAPP, FREDERICK G., 50 Church St., New York City. Dec., 1905.
CLARK, BRUCE L., Bacon Hall, Univ. of California, Berkeley, Calif. Dec., 1918.
CLARK, F. R., P. O. Box 2064, Tulsa, Okla. Dec., 1919.
CLARK, GLENN C., Continental Oil Co., Ponca City, Okla. Dec., 1927.
CLARK, THOMAS H., McGill University, Montreal, Canada. Dec., 1926.
CLARK, W. O., Naalehu, Kau, Hawaii. Dec., 1920.
CLARKE, EDWARD DE COURCY, University of Western Australia, Perth, Western Australia. Dec., 1924.
CLELAND, HERDMAN F., Williams College, Williamstown, Mass. Dec., 1905.
CLEMENTS, J. MORGAN, 27 Cedar St., New York City. Dec., 1894.
COBB, COLLIER, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
COLEMAN, ARTHUR P., Toronto University, Toronto, Canada. Dec., 1896.
COLLIER, ARTHUR J., U. S. Geological Survey, Washington, D. C. June, 1902.
COLLINS, WILLIAM H., Geological Survey, Ottawa, Canada. Dec., 1921.
COLONY, ROY JED, Columbia University, New York City. Dec., 1924.
CONDIT, D. DALE, 1221 Subway Terminal Bldg., Los Angeles, Calif. Dec., 1916.
CONDRA, GEORGE E., University of Nebraska, Lincoln, Neb. Dec., 1926.
CONNOLLY, JOSEPH P., State School of Mines, Rapid City, S. D. Dec., 1930.
COOK, CHAS. W., University of Michigan, Ann Arbor, Mich. Dec., 1915.
COOKE, C. WYTHE, U. S. Geological Survey, Washington, D. C. Dec., 1918.
CORBETT, CLIFTON S., % Gulf Cos., 21 State St., New York, N. Y. Dec., 1925.
CORYELL, H. N., Columbia University, New York, N. Y. Dec., 1928.
COSTE, EUGENE, 410 Royal Bank Bldg., Toronto, Canada. Dec., 1906.
COTTON, LEO ARTHUR, University of Sydney, Sydney, Australia. Dec., 1924.
CRAWFORD, RALPH DIXON, 1050 Tenth St., Boulder, Colo. Dec., 1916.
CRONEIS, CAREY, University of Chicago, Chicago, Ill. Dec., 1930.
CROSS, WHITMAN, 101 East Kirke St., Chevy Chase, Md. May, 1889.
CULVER, GARRY E., 310 Center Ave., Stevens Point, Wis. Dec., 1891.
CULVER, HAROLD E., State College, Pullman, Wash. Dec., 1925.
CUMINGS, EDGAR R., Indiana University, Bloomington, Ind. August, 1901.
CUSHMAN, J. A., Sharon, Mass. Dec., 1919.
DAKE, C. L., Missouri School of Mines, Rolla, Mo. Dec., 1920.
DALE, N. C., Hamilton College, Clinton, N. Y. Dec., 1920.
DALY, REGINALD A., Harvard University, Cambridge, Mass. Dec., 1905.
DANA, EDWARD SALISBURY, 24 Hillhouse Ave., New Haven, Conn. Dec., 1908.
*DARTON, NELSON H., U. S. Geological Survey, Washington, D. C.
DAVIS, E. F., 417 E. Randolph St., Glendale, Calif. Dec., 1920.
*DAVIS, WILLIAM M., Library, Museum, Cambridge, Mass.
DAY, ARTHUR LOUIS, Geophysical Laboratory, Washington, D. C. Dec., 1909.
DECKER, CHARLES ELIJAH, University of Oklahoma, Norman, Okla. Dec., 1924.
DE GOLYER, E. L., 65 Broadway, New York City. Dec., 1918.

De Lury, Justin S., University of Manitoba, Winnipeg, Canada. Dec., 1929.
de Moraes, Luciano J., Geological and Mineralogical Survey of Brazil, Rio de Janeiro, Brazil. Dec., 1930.
Deussen, Alexander, 1917 Post-Dispatch Bldg., Houston, Texas. Dec., 1916.
De Wolf, Frank Wilbridge, 3502 Audubon Place, Houston, Texas. Dec., 1909.
Dickerson, Roy E., 260 S. Broad St., Philadelphia, Pa. Dec., 1918.
Dobbin, Carroll E., U. S. Geological Survey, Washington, D. C. Dec., 1930.
Dodge, Richard E., Storrs, Conn. August, 1897.
Dolmage, Victor, 510 Pacific Bldg., Vancouver, B. C. Dec., 1922.
Drake, Noah Fields, Fayetteville, Ark. Dec., 1898.
Dresser, John A., 701 Eastern Townships Bank Bldg., Montreal, Canada. Dec., 1906.
Dunbar, C. O., Yale University, New Haven, Conn. Dec., 1920.
Eakle, Arthur S., University of California, Berkeley, Calif. Dec., 1899.
Eaton, Harry N., 742 W. First St., Elmira, N. Y. Dec., 1927.
Eckel, Edwin C., 1503 Decatur St. N. W., Washington, D. C. Dec., 1905.
Ellisor, Alva C., Humble Oil and Refining Co., Houston, Texas. Dec., 1929.
Emery, Wilson B., Casper, Wyoming. Dec., 1919.
*Emerson, Benjamin K., Amherst, Mass.
Emmons, Richard C., University of Wisconsin, Madison, Wis. Dec., 1930.
Emmons, William H., Univ. of Minnesota, Minneapolis, Minn. Dec., 1912.
*Fairchild, Herman L., University of Rochester, Rochester, N. Y.
Farrington, Oliver C., Field Museum of Natural History, Chicago, Ill. Dec., 1895.
Fath, A. E., Chrisman, Ill. Dec., 1920.
Fenneman, Nevin M., University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
Fenner, Clarence N., Geophysical Laboratory, Washington, D. C. Dec., 1911.
Ferguson, H. G., U. S. Geological Survey, Washington, D. C. Dec., 1920.
Fettke, Charles R., Carnegie Institute of Technology, Pittsburgh, Pa. Dec., 1924.
Field, Richard M., Princeton University, Princeton, N. J. Dec., 1926.
Finlay, George I., New York University, University Square, New York, N. Y. Dec., 1928.
Fisher, D. Jerome, University of Chicago, Chicago, Ill. Dec., 1929.
Flint, Richard Foster, Yale University, New Haven, Conn. Dec., 1929.
Foerste, August F., 129 Wroe Ave., Dayton, Ohio. Dec., 1899.
Fohs, Ferdinand Julius, 51 East 42nd St., New York, N. Y. Dec., 1923.
Ford, William E., Sheffield Scientific School, New Haven, Conn. Dec., 1915.
Foye, W. G., Wesleyan University, Middletown, Conn. Dec., 1919.
Fuller, Myron L., 60 Main St., Brockton, Mass. Dec., 1898.
Fuller, Richard E., University of Washington, Seattle, Wash. Dec., 1930.
Gale, Hoyt Stoddard, 1775 Hill Drive, Eagle Rock, Los Angeles, Calif. Dec., 1926.
Galloway, J. J., Columbia University, New York, N. Y. Dec., 1920.
Galpin, Sidney L., West Virginia University, Morgantown, W. Va. Dec., 1917.
Gane, Henry Stewart, Rural Del. No. 1, Santa Barbara, Calif. Dec., 1896.
Gardner, James H., 326 Beacon Life Bldg., Tulsa, Okla. Dec., 1911.
Gardner, Julia A., U. S. Geological Survey, Washington, D. C. Dec., 1920.

GEORGE, RUSSELL D., University of Colorado, Boulder, Colo. Dec., 1906.
GIDLEY, JAMES WILLIAM, U. S. Nat'l Museum, Washington, D. C. Dec., 1922.
GILBERT, GEOFFREY, 30 Chestnut Park, Toronto, Canada. Dec., 1928.
GILES, ALBERT W., University of Arkansas, Fayetteville, Ark. Dec., 1921.
GILL, ADAM CAPEN, Cornell University, Ithaca, N. Y. Dec., 1888.
GILLSON, JOSEPH L., 8060 Du Pont Bldg., Wilmington, Del. Dec., 1928.
GILLULY, JAMES, U. S. Geological Survey, Washington, D. C. Dec., 1927.
GILMORE, CHARLES WHITNEY, U. S. National Museum, Washington, D. C. Dec., 1924.
GLENN, L. C., 2111 Garland Ave., Nashville, Tenn. June, 1900.
GOLDMAN, MARCUS I., U. S. Geological Survey, Washington, D. C. Dec., 1916.
GOLDRING, WINIFRED, New York State Museum, Albany, N. Y. Dec., 1921.
GOLDTHWAIT, JAMES WALTER, Dartmouth College, Hanover, N. H. Dec., 1909.
GOODSPEED, GEORGE E., University of Washington, Seattle, Wash. Dec., 1930.
GORDON, CHARLES H., University Library, University of Tennessee, Knoxville, Tenn. August, 1893.
GORDON, CLARENCE E., Massachusetts Agricultural College, Amherst, Mass. Dec., 1913.
GOULD, CHARLES N., 215 S. Webster St., Norman, Okla. Dec., 1904.
GRABAU, AMADEUS W., Government University, Peiping, China. Dec., 1898.
GRANGER, WALTER, American Museum of Natural History, New York, N. Y. Dec., 1911.
GRANT, ULYSSES SHERMAN, Northwestern Univ., Evanston, Ill. Dec., 1890.
GRATON, LOUIS C., Rotch Building, Cambridge, Mass. Dec., 1913.
GREGORY, HERBERT E., Yale University, New Haven, Conn. August, 1901.
GREGORY, WILLIAM K., American Museum of Natural History, New York, N. Y. Dec., 1929.
GREENE, FRANK COOK, 1434 S. Cincinnati Ave., Tulsa, Okla. Dec., 1917.
GRIMSLEY, GEORGE P., 4405 Underwood Rd. (Guilford), Baltimore, Md. August, 1895.
GROUT, FRANK F., University of Minnesota, Minneapolis, Minn. Dec., 1918.
GRUNER, JOHN W., University of Minnesota, Minneapolis, Minn. Dec., 1923.
GUNTER, HERMAN, State Geological Survey, Tallahassee, Fla. Dec., 1926.
*GURLEY, WILLIAM, F. E. R., 6151 University Ave., Chicago, Ill. 1888-1900. Re-elected Dec., 1914.
HALBERSTADT, BAIRD, Pottsville, Pa. Dec., 1909.
HALL, GEORGE M., University of Tennessee, Knoxville, Tenn. Dec., 1926.
HANCE, J. H., Oregon State College, Corvallis, Ore. Dec., 1920.
HANCOCK, E. T., Teleajen Works, Romano-Americana, Ploesti, Rumania. Dec., 1919.
HANNA, MARCUS A., Gulf Production Co., P. O. Drawer C, Houston, Texas. Dec., 1930.
HARDER, E. C., 2900 New York Central Bldg., New York, N. Y. Dec., 1918.
HARES, C. J., 305 Franklin St., Denver, Colo. Dec., 1920.
HARRIS, GILBERT D., Cornell University, Ithaca, N. Y. Dec., 1903.
HARTNAGEL, CHRIS A., New York State Museum, Albany, N. Y. Dec., 1913.
HASTINGS, JOHN B., 8663 Cypress Ave., Southgate, Calif. May, 1889.
HAWLEY, JAMES E., Queen's University, Kingston, Ontario, Canada. Dec., 1930.

*HAWORTH, ERASMUS, 3116 East Second St., Wichita, Kans.
HAYES, ALBERT O., Rutgers University, New Brunswick, N. J. Dec., 1919.
HAYNES, WINTHROP PERRIN, 82 Avenue des Champs Elysees, Paris, France. Dec., 1926.
HEALD, K. C., 1161 Frick Bldg. Annex, Pittsburgh, Pa. Dec., 1920.
HENDERSON, JUNIUS, University of Colorado, Boulder, Colo. Dec., 1925.
HENNEN, RAY V., Morgantown, W. Va. Dec., 1914.
HERSHEY, OSCAR H., Crocker Bldg., San Francisco, Calif. Dec., 1909.
HESS, FRANK L., U. S. Bureau of Mines, Washington, D. C. Dec., 1921.
HEWETT, DONNEL F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
HILL, J. M., 2671 Shasta Road, Berkeley, Calif. Dec., 1920.
*HILL, ROBERT T., Hotel Commodore, Los Angeles, Calif.
HILLS, THOMAS MCDOUGALL, Vassar College, Poughkeepsie, N. Y. Dec., 1924.
HINDS, HENRY, Room 2749, 420 Lexington Ave., New York, N. Y. Dec., 1912.
HINDS, NORMAN E. A., University of California, Berkeley, Calif. Dec., 1930.
HINTZE, FERDINAND FRIIS, University of Utah, Salt Lake City, Utah. Dec., 1917.
HOBBS, WILLIAM H., University of Michigan, Ann Arbor, Mich. August, 1891.
HODGE, EDWIN T., University of Oregon, Eugene, Ore. Dec., 1927.
HOFFMEISTER, J. E., University of Rochester, Rochester, N. Y. Dec., 1929.
HOLDEN, ROY J., Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.
HOLLAND, WILLIAM JACOB, Carnegie Museum, Pittsburgh, Pa. Dec., 1910.
HOLLICK, ARTHUR, N. Y. Botanical Garden, New York, N. Y. August, 1898.
HONESS, CHARLES W., Gypsy Oil Co., Tulsa, Okla. Dec., 1927.
HOOTS, HAROLD W., 1113 Union Oil Bldg., Los Angeles, Calif. Dec., 1928.
HOPKINS, O. B., Internat. Petr. Co., Ltd., 56 Church St., Toronto, Canada. Dec., 1919.
HOPKINS, THOMAS C., Syracuse University, Syracuse, N. Y. Dec., 1894.
HOTCHKISS, WILLIAM OTIS, College of Mines, Houghton, Mich. Dec., 1911.
HOWARD, W. V., University of Illinois, Urbana, Ill. Dec., 1929.
HOWE, ERNEST, Litchfield, Conn. Dec., 1903.
HOWELL, BENJAMIN F., Princeton University, Princeton, N. J. Dec., 1926.
HUBBARD, BELA, Carter Oil Co., P. O. Box 2045, Tulsa, Okla. Dec., 1929.
HUBBARD, GEORGE D., Oberlin College, Oberlin, Ohio. Dec., 1914.
HUDSON, GEORGE H., 39 Broad Street, Plattsburg, N. Y. Dec., 1917.
HULIN, CARLTON D., University of California, Berkeley, Calif. Dec., 1929.
HUME, GEORGE S., Geological Survey of Canada, Ottawa, Canada. Dec., 1923.
HUNT, WALTER F., University of Michigan, Ann Arbor, Mich. Dec., 1914.
HUNTINGTON, ELLSWORTH, Yale University, New Haven, Conn. Dec., 1906.
HUSSAKOF, LOUIS, 1537 50th St., Brooklyn, N. Y. Dec., 1910.
HYDE, J. E., Western Reserve University, Cleveland, Ohio. Dec., 1916.
JACKSON, ROBERT T., Peterborough, N. H. August, 1894.
JACOBS, ELBRIDGE C., University of Vermont, Burlington, Vt. Dec., 1921.
JEFFERSON, MARK S. W., Michigan State Normal College, Ypsilanti, Mich. Dec., 1904.
JENKINS, OLAF P., 630 Amherst St., Sta. A, Palo Alto, Calif. Dec., 1921.
JOHANNSEN, ALBERT, University of Chicago, Chicago, Ill. Dec., 1908.
JOHNSON, B. L., U. S. Bureau of Mines, Washington, D. C. Dec., 1919.
JOHNSON, DOUGLAS WILSON, Columbia University, New York, N. Y. Dec., 1906.

JOHNSON, ROSWELL H., University of Pittsburgh, Pittsburgh, Pa. Dec., 1918.
JONAS, ANNA I., Room 4230, U. S. Geological Survey, Washington, D. C. Dec., 1922.
JONES, J CLAUDE, University of Nevada, Reno, Nev. Dec., 1927.
KAY, GEORGE FREDERICK, State Univ. of Iowa, Iowa City, Iowa. Dec., 1908.
KEITH, ARTHUR, U. S. Geological Survey, Washington, D. C. May, 1889.
KERR, PAUL F., Columbia University, New York, N. Y. Dec., 1927.
KEW, W. S. W., 1215 N. Howard St., Glendale, Calif. Dec., 1920.
KEYES, CHARLES ROLLIN, Route 1, Box 178, Tucson, Ariz. August, 1890.
KINDLE, EDWARD M., Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
KIRK, CHARLES T., 1226 S. Newport St., Tulsa, Okla. Dec., 1915.
KIRK, EDWIN, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KIRKHAM, V. R. D., 501 Townsend, Lansing, Mich. Dec., 1927.
KNAPPEN, RUSSELL S., P. O. Box 2044, Tulsa, Okla. Dec., 1926.
KNIGHT, CYRIL WORKMAN, Nipissing Mining Co., Ltd., Cobalt, Ontario, Canada. Dec., 1911.
KNIGHT, SAMUEL H., University of Wyoming, Laramie, Wyo. Dec., 1930.
KNOPF, ADOLPH, Yale Station, New Haven, Conn. Dec., 1911.
KNOPF, ELEANORA BLISS, 105 East Rock Road, New Haven, Conn. Dec., 1919.
KRAUS, EDWARD HENRY, Univ. of Michigan, Ann Arbor, Mich. June, 1902.
KUMMEL, HENRY B., Trenton, N. J. Dec., 1895.
*KUNZ, GEORGE F., 401 Fifth Ave., New York, N. Y.
LADD, H. S., Apartado 234, Maracaibo, Venezuela. Dec., 1929.
LAHEE, FREDERIC H., American Exchange Natl. Bank Bldg., Dallas, Texas. Dec., 1917.
LAMAR, JOHN E., State Geological Survey, Urbana, Ill. Dec., 1929.
LANDES, HENRY, University of Washington, University Station, Seattle, Wash. Dec., 1908.
LANDES, KENNETH K., University of Kansas, Lawrence, Kans. Dec., 1929.
LANE, ALFRED C., Tufts College, Boston, Mass. Dec., 1889.
LARSEN, ESPER S., JR., Geol. Mus., Harvard Univ., Cambridge, Mass. Dec., 1914.
LAWSON, ANDREW C., University of California, Berkeley, Calif. May, 1889.
LEES, JAMES H., Iowa Geological Survey, Des Moines, Iowa. Dec., 1914.
LEIGHTON, MORRIS M., Illinois Geological Survey, Urbana, Ill. Dec., 1921.
LEITH, CHARLES K., University of Wisconsin, Madison, Wis. Dec., 1902.
LEONARD, ARTHUR G., State University of North Dakota, Grand Forks, N. Dak. Dec., 1901.
LEVERETT, FRANK, Ann Arbor, Mich. August, 1890.
LEVORSEN, ARVILLE I., Box 1830, Tulsa, Okla. Dec., 1930.
LEWIS, JOSEPH VOLNEY, Administration Bldg., Burnham Park, Chicago, Ill. Dec., 1906.
LIDDLE, RALPH ALEXANDER, The Pure Oil Co., P. O. Box 1007, Fort Worth, Texas. Dec., 1921.
LINDGREN, WALDEMAR, Massachusetts Institute of Technology, Cambridge, Mass. August, 1890.
LINK, THEODORE A., Imperial Ohio Co., Ltd., Calgary, Alberta, Canada. Dec., 1929.

LISBOA, MIGUEL A. R., Caixa postal 829, Ave. Rio Branco 46-V, Rio de Janeiro, Brazil. Dec., 1913.
LITTLE, HOMER P., Clark University, Worcester, Mass. Dec., 1918.
LLOYD, E. R., P. O. Box 652, Roswell, N. Mex. Dec., 1919.
LOBECK, ARMIN KOHL, Columbia University, New York, N. Y. Dec., 1924.
LOCKE, AUGUSTUS, 788 Mills Bldg., San Francisco, Calif. Dec., 1927.
LOGAN, WILLIAM N., Indiana University, Bloomington, Ind. Dec., 1917.
LONGWELL, CHESTER R., Yale University, New Haven, Conn. Dec., 1923.
LONSDALE, JOHN T., University of Texas, Austin, Texas. Dec., 1928.
LOOMIS, FREDERICK BREWSTER, Amherst College, Amherst, Mass. Dec., 1909.
LOUDERBACK, GEORGE D., University of California, Berkeley, Calif. June, 1902.
LOUGHLIN, GERALD F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
LOVERING, THOMAS S., U. S. Geological Survey, Washington, D. C. Dec., 1927.
LOW, ALBERT P., 154 McLaren St., Ottawa, Canada. Dec., 1905.
LULL, RICHARD SWANN, Yale University, New Haven, Conn. Dec., 1909.
LUPTON, CHARLES T., 617 Gilpin St., Denver, Colo. Dec., 1916.
MCCALLIE, SAMUEL WASHINGTON, Atlanta, Ga. Dec., 1909.
MCCASKEY, HIRAM D., Central Point, Oregon. Dec., 1904.
MCCAUGHEY, WILLIAM J., Ohio State University, Columbus, Ohio. Dec., 1929.
MCCONNELL, RICHARD G., Rideau Club, Ottawa, Canada. May, 1889.
MCCOY, ALEX. W., 919 E. Grand Ave., Ponca City, Okla. Dec., 1922.
MACCARTHY, GERALD R., University of North Carolina, Chapel Hill, N. C. Dec., 1929.
MACDONALD, DONALD F., Drawer 1087, Hopewell, Va. Dec., 1915.
MACFARLANE, JAMES RIEMAN, Woodland Road, Pittsburgh, Pa. August, 1891.
MACKAY, BERTRAM R., Geological Survey, Ottawa, Canada. Dec., 1922.
MCLAUGHLIN, DONALD H., Rotch Bldg., Harvard University, Cambridge, Mass. Dec., 1922.
MCLEARN, FRANK HARRIS, Geological Survey, Ottawa, Canada. Dec., 1923.
MALOTT, CLYDE A., Indiana University, Bloomington, Ind. Dec., 1926.
MANSFIELD, GEORGE R., 2067 Park Rd. N. W., Washington, D. C. Dec., 1909.
MARBUT, CURTIS F., Bureau of Soils, Washington, D. C. August, 1897.
MARSTERS, VERNON F., P. O. Box 513, Winnsboro, Texas. August, 1892.
MARTENS, J. H. C., State Geological Survey, Morgantown, W. Va. Dec., 1929.
MARTIN, GEORGE C., 3126 38th Street, Washington, D. C. June, 1902.
MARTIN, LAWRENCE, Library of Congress, Washington, D. C. Dec., 1909.
MATHER, KIRTLEY F., Harvard Geological Museum, Cambridge, Mass. Dec., 1918.
MATHEWS, EDWARD B., Johns Hopkins University, Baltimore, Md. Aug., 1895.
MATSON, GEORGE C., 1534 East 17th Place, Tulsa, Okla. Dec., 1918.
MATTHES, FRANCOIS E., U. S. Geol. Survey, Washington, D. C. Dec., 1914.
MAURY, CARLOTTA J., 50-A Locust Hill Ave., Yonkers, N. Y. Dec., 1920.
MAYNARD, THOMAS POOLE, 759 Myrtle St., N. E., Atlanta, Ga. Dec., 1914.
MEAD, WARREN JUDSON, University of Wisconsin, Madison, Wis. Dec, 1916.
MEHL, MAURICE G., University of Missouri, Columbia, Mo. Dec., 1922.
MEINZER, OSCAR E., U. S. Geological Survey, Washington, D. C. Dec., 1916.
MENDENHALL, WALTER C., U. S. Geol. Survey, Washington, D. C. June, 1902.
MERRIAM, JOHN C., Carnegie Institution, Washington, D. C. August, 1895.

MERTIE, JOHN BEAVER, JR., U. S. Geological Survey, Washington, D. C. Dec., 1923.

MERWIN, HERBERT E., Geophysical Laboratory, Washington, D. C. Dec., 1914.

MILLER, BENJAMIN L., Lehigh University, Bethlehem, Pa. Dec., 1904.

MILLER, WILLIAM JOHN, University of California at Los Angeles, Los Angeles, Calif. Dec., 1909.

MISER, HUGH D., U. S. Geological Survey, Washington, D. C, Dec., 1916.

MOFFITT, FRED HOWARD, U. S. Geological Survey, Washington, D. C. Dec., 1912.

MONNETT, VICTOR E., University of Oklahoma, Norman, Okla. Dec., 1926.

MOORE, ELWOOD S., University of Toronto, Toronto, Canada. Dec., 1911.

MOORE, RAYMOND C., University of Kansas, Lawrence, Kans. Dec., 1921.

MOOK, CHARLES C., Metuchen, N. J. Dec., 1922.

MORGAN, GEORGE D., Ricker & Dodson Bldg., San Angelo, Texas. Dec., 1927.

MORRIS, F. K., Massachusetts Institute of Technology, Cambridge, Mass. Dec., 1927.

MORSE, WILLIAM C., Agricultural and Mechanical College, Miss. Dec., 1925.

MOULTON, GAIL F., P. O. Box 1760, Houston, Texas. Dec., 1929.

NELSON, W. A., University, Va. Dec., 1920.

NEWLAND, DAVID HALE, 94 Menand Road, Albany, N. Y. Dec., 1906.

NOBLE, LEVI F., Valyermo, Calif. Dec., 1916.

NOÉ, ADOLF C., University of Chicago, Chicago, Ill. Dec., 1927.

NORTON, WILLIAM H., Cornell College, Mount Vernon, Iowa. Dec., 1895.

NIINOMY, KUNITARO, Teachers College, Dairen, Manchuria, China. Dec., 1929.

O'CONNELL (SHEARON), MARJORIE, 137-70 Westgate Ave., Springfield Gardens, L. I. Dec., 1919.

OGILVIE, IDA HELEN, Barnard College, Columbia University, New York, N. Y. Dec., 1906.

O'HARRA, CLEOPHAS C., South Dakota School of Mines, Rapid City, S. Dak. Dec., 1904.

OHERN, DANIEL WEBSTER, 515 W. 14th St., Oklahoma City, Okla. Dec., 1911.

OLSSON, AXEL A., 48 Woodside Ave., Gloversville, N. Y. Dec., 1929.

O'Neill, J. J., McGill University, Montreal, Canada. Dec., 1920.

OSBORN, HENRY F., American Museum of Natural History, New York, N. Y. August, 1894.

OVERBECK, ROBERT M., c/o Caracoles Tin Co. of Bolivia, Casilla No. 674, La Paz, Bolivia, South America. Dec., 1921.

PACK, FREDERICK J., University of Utah, Salt Lake City, Utah. Dec., 1926.

PACK, ROBERT W., Box 790, Beaumont, Texas. Dec., 1916.

PAIGE, SIDNEY, 2911 Thirty-third Place, Washington, D. C. Dec., 1911.

PALACHE, CHARLES, Harvard University, Cambridge, Mass. August, 1897.

PALMER, HAROLD S., University of Hawaii, Honolulu, Hawaii. Dec., 1927.

PARKS, WILLIAM A., University of Toronto, Toronto, Canada. Dec., 1906.

PARSONS, ARTHUR L., University of Toronto, Toronto, Canada. Dec., 1928.

PENROSE, RICHARD A. F., JR., Bullitt Bldg., Philadelphia, Pa. May, 1889.

PERKINS, EDWARD H., Colby College, Waterville, Me. Dec., 1929.

PERKINS, GEORGE H., University of Vermont, Burlington, Vt. June, 1902.

PERRY, JOSEPH H., 276 Highland St., Worcester, Mass. Dec., 1888.

PHALEN, WILLIAM C., Drawers 1 and 2, Syracuse, N. Y. Dec., 1912.

PHILLIPS, ALEXANDER H., Princeton University, Princeton, N. J. Dec., 1914.
PIPER, ARTHUR M., U. S. Geological Survey, Washington, D. C. Dec., 1928.
PLUMMER, FREDERICK B., Bureau of Economic Geology, Austin, Texas. Dec., 1925.
POGUE, JOSEPH E., 42 West 12th St., New York City. Dec., 1911.
POHL, ERWIN R., Horse Cave, Tenn. Dec., 1930.
POWERS, SIDNEY, Amerada Petroleum Corp., Tulsa, Okla. Dec., 1920.
PRATT, JOSEPH H., North Carolina Geol. Survey, Chapel Hill, N. C. Dec., 1898.
PRATT, W. E., Humble Oil and Refining Co., Houston, Texas. Dec., 1920.
PRICE, W. ARMSTRONG, P. O. Box 112, Corpus Christi, Texas. Dec., 1916.
PRINDLE, LOUIS M., U. S. Geological Survey, Washington, D. C. Dec., 1912.
PROUTY, WILLIAM F., Univ. of North Carolina, Chapel Hill, N. C. Dec., 1911.
QUIRKE, TERENCE T., University of Illinois, Urbana, Ill. Dec., 1921.
RANSOME, FREDERICK L., California Institute of Technology, Pasadena, Calif. August, 1895.
RAYMOND, PERCY EDWARD, Museum of Comparative Zoology, Cambridge, Mass. Dec., 1907.
REBER, LOUIS E., Box 455, Jerome, Ariz. Dec., 1923.
REED, RALPH D., 1110 Glendon Way, South Pasadena, Calif. Dec., 1927.
REEDS, CHESTER A., American Museum of Natural History, New York, N. Y. Dec., 1913.
REESIDE, JOHN B., JR., U. S. Geological Survey, Hyattsville, Md. Dec., 1921.
REEVES, FRANK, U. S. Geological Survey, Washington, D. C. Dec., 1924.
REGER, DAVID B., Box 816, Morgantown, W. Va. Dec., 1918.
REID, HARRY FIELDING, Johns Hopkins University, Baltimore, Md. Dec., 1892.
REINECKE, LEOPOLD, P. O. Box 2682, Johannesburg, Transvaal, South Africa. Dec., 1916.
RENICK, B. COLEMAN, Vacuum Oil Co., Box 1052, San Antonio, Texas. Dec., 1926.
RESSER, CHARLES E., U. S. National Museum, Washington, D. C. Dec., 1926.
RICE, HAMILTON, 901 Fifth Ave., New York, N. Y. Dec., 1929.
RICH, JOHN LYON, Box 3, Ottawa, Kans. Dec., 1912.
RICHARDS, R. W., Apartado 85, Maracaibo, Venezuela. Dec., 1920.
RICHARDSON, CHARLES H., Syracuse University, Syracuse, N. Y. Dec., 1899.
RICHARDSON, GEORGE B., U. S. Geol. Survey, Washington, D. C. Dec., 1908.
RICHARZ, STEPHEN, St. Mary's College, Techny, Ill. Dec., 1926.
RIES, HEINRICH, Cornell University, Ithaca, N. Y. Dec., 1893.
RIGGS, ELMER S., Field Museum of Natural History, Chicago, Ill. Dec., 1911.
ROBERTS, JOSEPH K., University of Virginia, Charlottesville, Va. Dec., 1926.
RODDY, H. JUSTIN, 645 W. Chestnut St., Lancaster, Pa. Dec., 1919.
ROGERS, AUSTIN F., Stanford University, Calif. Dec., 1918.
ROSE, BRUCE, Queen's University, Kingston, Ontario, Canada. Dec., 1916.
ROSS, CLARENCE, U. S. Geological Survey, Washington, D. C. Dec., 1926.
RUBEY, WILLIAM W., U. S. Geological Survey, Washington, D. C. Dec., 1927.
RUEDEMANN, RUDOLF, New York State Museum, Albany, N. Y. Dec., 1905.
RUSSELL, RICHARD J., Louisiana State University, Baton Rouge, La. Dec., 1930.
RUTLEDGE, JOHN JOSEPH, State Bureau of Mines, 22 Light St., Baltimore, Md. Dec., 1911.

SALES, RENO H., Anaconda Copper Mining Co., Butte, Mont. Dec., 1916.
SAMPSON, EDWARD, Princeton University, Princeton, N. J. Dec., 1924.
SARDESON, FREDERICK W., 414 Harvard St., S. E., Minneapolis, Minn. Dec. 1892.
SAYLES, ROBERT WILCOX, Harvard University, Chestnut Hill, Mass. Dec., 1917.
SAVAGE, THOMAS EDMUND, University of Illinois, Urbana, Ill. Dec., 1907.
SCHALLER, WALDEMAR T., U. S. Geol. Survey, Washington, D. C. Dec., 1918.
SCHENCK, HUBERT G., Stanford University, Calif. Dec., 1927.
SCHNEIDER, HYRUM, University of Utah, Salt Lake City, Utah. Dec., 1927.
SCHOEWE, WALTER H., 1631 Illinois St., Lawrence, Kansas. Dec., 1927.
SCHOFIELD, S. J., University of British Columbia, Vancouver, B. C. Dec., 1918.
SCHRADER, FRANK C., U. S. Geological Survey, Washington, D. C. Aug., 1901.
SCHUCHERT, CHARLES, Yale University, New Haven, Conn. August, 1895.
SCHULTZ, ALFRED R., 800 Vine Street, Hudson, Wis. Dec., 1912.
SCHWARTZ, GEORGE M., Univ. of Minnesota, Minneapolis, Minn. Dec., 1923.
SCOTT, GAYLE, Texas Christian University, Fort Worth, Texas. Dec., 1929.
SCOTT, IRVING D., University of Michigan, Ann Arbor, Mich. Dec., 1923.
SCOTT, WILLIAM B., Princeton University, Princeton, N. J. August, 1892.
SEAMAN, ARTHUR E., Michigan College of Mines, Houghton, Mich. Dec., 1904.
SEARS, JULIAN DUCKER, 209 E. Underwood St., Chevy Chase, Md. Dec., 1924.
SELLARDS, ELIAS H., University of Texas, Austin, Texas. Dec., 1905.
SEMMES, DOUGLAS R., 1601 Milam Bldg., San Antonio, Texas. Dec., 1921.
SHALER, MILLARD K., 66 Rue Des Colonies, Brussels, Belgium. Dec., 1914.
SHATTUCK, GEORGE BURBANK, Mt. Royal Station, Baltimore, Md. Aug., 1899.
SHAW, EUGENE W., Room 1560, 81 New Street, New York, N. Y. Dec., 1912.
SHEDD, SOLON, Box 1888, Stanford University, Calif. Dec., 1904.
SHEPARD, EDWARD M., 1403 Benton Ave., Springfield, Mo. August, 1901.
SHEPARD, FRANCIS P., University of Illinois, Urbana, Ill. Dec., 1927.
SHIMEK, BOHUMIL, University of Iowa, Iowa City, Iowa. Dec., 1904.
SHIMER, HERVEY WOODBURN, Massachusetts Institute of Technology, Cambridge, Mass. Dec., 1910.
SHULER, E. W., South Methodist University, Dallas, Texas. Dec., 1920.
*SIMONDS, FREDERICK W., University of Texas, Austin, Texas.
SIMPSON, GEORGE G., American Museum of Natural History, New York, N. Y. Dec., 1930.
SIMPSON, HOWARD E., University of North Dakota, Grand Forks, N. Dak. Dec., 1923.
SINCLAIR, WILLIAM JOHN, Princeton University, Princeton, N. J. Dec., 1906.
SINGEWALD, JOSEPH T., JR., Johns Hopkins University, Baltimore, Md. Dec., 1911.
SISLER, JAMES D., West Virginia Geological Survey, Morgantown, W. Va. Dec., 1930.
SMITH, BURNETT, West Lake St., Skaneateles, N. Y. Dec., 1911.
SMITH, EDWARD S. C., Union College, Schenectady, N. Y. Dec., 1928.
SMITH, GEORGE OTIS, U. S. Geological Survey, Washington, D. C. Aug., 1897.
SMITH, PHILIP S., U. S. Geological Survey, Washington, D. C. Dec., 1909.
SMITH, RICHARD A., Biological Survey of Michigan, Lansing, Mich. Dec., 1921.
SMITH, STANLEY, University of Bristol, Bristol, England. Dec., 1922.

SMITH, WARREN DU PRÉ, University of Oregon, Eugene, Ore. Dec., 1909.
SMITH, W. S. TANGIER, 640 Tennyson Ave., Palo Alto, Calif. June, 1902.
SMYTH, CHARLES H., JR., Princeton University, Princeton, N. J. Aug., 1892.
SMYTH, HENRY L., 456 Belmont St., Watertown, Mass. August, 1894.
SNIDER, LUTHER C., 110 Crescent Ave., Leonia, N. J. Dec., 1927.
SOMERS, R. E., Gulf Co., Box 1214, Pittsburgh, Pa. Dec., 1919.
SOPER, EDGAR K., 845 Muirfield Road, Los Angeles, California. Dec., 1918.
SOSMAN, R. B., Federal Shipbuilding and Dry Dock Co., Kearny, N. J. Dec., 1920.
SPEIGHT, ROBERT, Canterbury College, Christ Church, New Zealand. Dec., 1916.
SPENCER, ARTHUR COE, U. S. Geological Survey, Washington, D. C. Dec., 1896.
SPIEKER, EDMUND MAUTE, State University of Ohio, Columbus, Ohio. Dec., 1924.
SPURR, JOSIAH E., c/o Engineering and Mining Journal, 10th Ave. and 36th St., New York, N. Y. Dec., 1894.
STANLEY-BROWN, JOSEPH, 151 Quentin St., Kew Gardens, L. I., N. Y. August, 1892.
STANTON, TIMOTHY W., U. S. Nat'l Museum, Washington, D. C. August, 1891.
STAUFFER, CLINTON R., Univ. of Minnesota, Minneapolis, Minn. Dec., 1911.
STEARNS, HAROLD T., U. S. Geological Survey, Washington, D. C. Dec., 1927.
STEBINGER, EUGENE, JR., 719 Edificio Banco Boston, Buenos Aires, Argentina. Dec., 1916.
STEIDTMANN, EDWARD, Virginia Military Institute, Lexington, Va. Dec., 1916.
STEPHENSON, LLOYD W., U. S. Geological Survey, Washington, D. C. Dec., 1911.
STERRETT, DOUGLAS B., "Springfield," Pierce Mill Rd., Washington, D. C. Dec., 1929.
STOCK, CHESTER, California Institute of Technology, Pasadena, Calif. Dec., 1927.
STOLLER, JAMES HOUGH, Galway, Saratoga County, N. Y. Dec., 1917.
STONE, RALPH WALTER, State Geological Survey, Harrisburg, Pa. Dec., 1912.
STOSE, GEORGE WILLIS, U. S. Geological Survey, Washington, D. C. Dec., 1908.
STOUT, WILBER, Geological Survey of Ohio, Columbus, Ohio. Dec., 1918.
SUSSMILCH, CARL ADOLPH, East Sydney Technical College, Darlinghurst, Sydney, Australia. Dec., 1925.
SWANSON, CLARENCE O., College of Mining and Technology, Houghton, Mich. Dec., 1929.
SWARTZ, CHARLES K., Johns Hopkins University, Baltimore, Md. Dec., 1908.
SWARTZ, JOEL H., University of North Carolina, Chapel Hill, N. C. Dec., 1927.
SWINNERTON, A. C., Antioch College, Yellow Springs, Ohio. Dec., 1928.
TABER, STEPHEN, University of South Carolina, Columbia, S. C. Dec., 1914.
TAFF, JOSEPH A., 629 Cooper St., Palo Alto, Calif. August, 1895.
TALBOT, MIGNON, Mount Holyoke College, South Hadley, Mass. Dec., 1913.
TALIAFERRO, NICHOLAS L., University of California, Berkeley, Calif. Dec., 1929.
TALMAGE, JAMES E., 47 E. South Temple St., Salt Lake City, Utah. Dec., 1897.
TANTON, THOMAS L., Geological Survey, Ottawa, Canada. Dec., 1927.
TARR, WILLIAM ARTHUR, 704 Westwood Ave., Columbia, Mo. Dec., 1917.
TAYLOR, FRANK B., 420 Downing Ave., Fort Wayne, Ind. Dec., 1895.

THALMAN, HANS E., Schwarztorstr. 22, Berne, Switzerland. Dec., 1930.
THIEL, GEORGE A., University of Minnesota, Minneapolis, Minn. Dec., 1925.
THOM, WILLIAM TAYLOR, JR., Princeton University, Princeton, N. J. Dec., 1924.
THOMPSON, DAVID G., U. S. Geological Survey, Washington, D. C. Dec., 1928.
THORPE, MALCOLM R., 1463 Yale Station, New Haven, Conn. Dec,, 1923.
THWAITES, FREDRIK T., Science Hall, Madison, Wis. Dec., 1925.
TOLMACHOFF, I. P., Carnegie Museum, Pittsburgh, Pa. Dec., 1927.
TOMLINSON, CHARLES WELDON, 1610 Bixby Ave., Ardmore, Okla. Dec., 1917.
TRASK, PARKER D., Prospect Apartments, Princeton, N. J. Dec., 1927.
TROWBRIDGE, ARTHUR C., State Univ. of Iowa, Iowa City, Iowa. Dec., 1913.
TROXELL, EDWARD L., Trinity College, Hartford, Conn. Dec., 1923.
*TURNER, HENRY W., Ross, Marin County, Calif.
TWENHOFEL, WILLIAM H., University of Wisconsin, Madison, Wis. Dec., 1913.
TYRRELL, JOSEPH B., 25 King St., W., Toronto, Canada. May, 1889.
UDDEN, JOHAN A., University of Texas, Austin, Texas. August, 1897.
*ULRICH, EDWARD O., U. S. Geological Survey, Washington, D. C. 1888-1897. Re-elected Dec., 1903.
UMPLEBY, JOSEPH B., City Nat'l Bank Bldg., Norman, Okla. Dec., 1913.
*UPHAM, WARREN, Minnesota Historical Society, St. Paul, Minn.
VAN DER GRACHT, WILLIAM A. J., M. van Waterschoot, Schloss Hainfeld, Feldbach, Austria. Dec., 1928.
VAN HORN, F. R., Case School of Applied Science, Cleveland, Ohio. Dec., 1898.
VAN TUYL, FRANCIS M., Colorado School of Mines, Golden, Colo. Dec., 1917.
VAUGHAN, T. WAYLAND, Scripps Institution, La Jolla, Calif. August, 1896.
VEATCH, ARTHUR CLIFFORD, 7 Central Drive, Port Washington, N. Y. Dec., 1906.
VISHER, STEPHEN S., 817 E. Second St., Bloomington, Ind. Dec., 1923.
VON ENGELN, OSCAR D., Cornell University, Ithaca, N. Y. Dec., 1927.
WADE, BRUCE, State Geological Survey, Nashville, Tenn. Dec., 1920.
WALKER, THOMAS L., University of Toronto, Toronto, Canada. Dec., 1903.
WALLACE, ROBERT C., University of Alberta, Edmonton, Alberta, Canada. Dec., 1930.
WANDKE, ALFRED, United Mines Co., Guanajuato, Mexico. Dec., 1928.
WARD, FREEMAN, 40 McCartney St., Easton, Pa. Dec., 1925.
WARD, LEONARD KEITH, Department of Mines, Adelaide, South Australia. Dec., 1924.
WARING, GERALD A., 1125 S. Carson Ave., Tulsa, Okla. Dec., 1921.
WARREN, CHARLES H., Yale University, New Haven, Conn. Dec., 1901.
WARREN, PERCIVAL S., University of Alberta, Edmonton, Alberta, Canada. Dec., 1930.
WASHBURNE, C. W., 149 Broadway, New York, N. Y. Dec., 1919.
WASHINGTON, HENRY S., Geophysical Laboratory, Washington, D. C. Aug., 1896.
WEAVER, CHARLES E., University of Washington, Seattle, Wash. Dec., 1913.
WEED, WALTER H., Post Road, Scarsdale, N. Y. May, 1889.
WEGEMANN, CARROLL H., Pan American Exploration Co., 122 E. 42nd St., New York, N. Y. Dec., 1912.

WEIDMAN, SAMUEL, 512 Lahoma St., Norman, Okla. Dec., 1903.
WELLER, J. MARVIN, State Geological Survey, Urbana, Ill. Dec., 1930.
WELLS, ROGER C., U. S. Geological Survey, Washington, D. C. Dec., 1921.
WENTWORTH, CHESTER K., Washington University, St. Louis, Mo. Dec., 1923.
WESTGATE, LEWIS G., 124 Oak Hill Ave., Delaware, Ohio. August, 1894.
WHERRY, EDGAR T., University of Pennsylvania, Philadelphia, Pa. Dec., 1915.
WHITE, DAVID, U. S. National Museum, Washington, D. C. May, 1889.
WHITE, LUTHER H., 211 E. Jasper St., Tulsa, Okla. Dec., 1928.
WHITLOCK, H. P., Amer. Museum of Natural History, N. Y. City. Dec., 1920.
WHITMAN, ALFRED R., University of California, Los Angeles, Calif. Dec., 1928.
WHITNEY, FRANCIS L., University of Texas, Austin, Texas. Dec., 1923.
WIELAND, GEORGE REBER, Yale University, New Haven, Conn. Dec., 1910.
WILLARD, BRADFORD, Topographic and Geologic Survey, Harrisburg, Pa. Dec., 1930.
*WILLIAMS, EDWARD H., JR., Woodstock, Vt.
WILLIAMS, IRA A., 821 Spalding Bldg., Portland, Ore. Dec., 1905.
WILLIAMS, MERTON YARWOOD, Univ. of British Columbia, Vancouver, B. C. Dec., 1916.
WILLIS, BAILEY, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1889.
WILSON, ALFRED W. G., Department of Mines, Ottawa, Canada. June, 1902.
WILSON, ELDRED DEWEY, Arizona Bureau of Mines, Tucson, Ariz. Dec., 1929.
WILSON, MORLEY EVANS, Geological Survey, Ottawa, Canada. Dec., 1916.
WINCHELL, ALEXANDER N., University of Wisconsin, Madison, Wis. Aug., 1901.
*WINSLOW, ARTHUR, 131 State St., Boston, Mass.
WOLFF, JOHN E., 360 S. Grand Ave., Pasadena, Calif. Dec., 1889.
WOOD, HARRY OSCAR, 200 N. San Rafael Ave., Pasadena, Calif. Dec., 1922.
WOOD, HORACE ELMER, II, New York University, University Square, New York, N. Y. Dec., 1930.
WOODFORD, ALFRED O., Pomona College, Claremont, Calif. Dec., 1927.
WOODMAN, JOSEPH E., New York University, New York, N. Y. Dec., 1905.
WOODRING, WENDELL P., U. S. Geological Survey, Washington, D. C. Dec., 1921.
WOODRUFF, E. G., 1611 S. Detroit St., Tulsa, Okla. Dec., 1922.
WOOLNOUGH, WALTER GEORGE, Home and Territories Dept., Canberra, F. C. 2, Australia. Dec., 1924.
WRATHER, WILLIAM E., 4300 Overhill Drive, Dallas, Texas. Dec., 1923.
WRIGHT, CHARLES WILL, 109 Brookside Drive, Chevy Chase, Md. Dec., 1909.
WRIGHT, FREDERIC E., Geophysical Laboratory, Washington, D. C. Dec., 1903.
ZIES, EMANUEL G., Geophysical Laboratory, Washington, D. C. Dec., 1930.

CORRESPONDENTS DECEASED

CAPELLINI, GIOVANNI. Died 1924.
CREDNER, HERMAN. Died July 22, 1913.
DE STEFANI, CARLO. Died Dec. 12, 1924.
GEIKIE, SIR ARCHIBALD. Died Nov., 1924.
MICHEL-LÉVY, A. Died September, 1911.
KAYSER, EMANUEL. Died Nov. 29, 1927.
KILIAN, W. Died 1926.
ROSENBUSCH, H. Died January 20, 1914.
SUESS, EDWARD. Died April 20, 1914.
TEALL, SIR J. J. H. Died July 2, 1924.
TIETZE, EMIL. Died March 5, 1931.
TSCHERNYSCHEW, TH. Died Jan. 15, 1914.
ZIRKEL, FERDINAND. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellows (see article II of By-Laws)

AMI, HENRY M. Died Jan. 4, 1931.
*ASHBURNER, CHAS. A. Died Dec. 24, 1889.
BARLOW, ALFRED E. Died May 28, 1914.
BARRELL, JOSEPH. Died May 4, 1919.
BEECHER, CHARLES E. Died Feb. 14, 1904.
*BECKER, GEORGE F. Died April 20, 1919.
BELL, ROBERT. Died June 18, 1917.
BICKMORE, ALBERT S. Died Aug. 12, 1914.
BLAKE, WM. PHIPPS. Died May 21, 1910.
BOWMAN, AMOS. Died June 18, 1894.
BOWNOCKER, JOHN A. Died Oct. 20, 1928.
*BRANNER, JOHN C. Died March 1, 1922.
BROOKS, ALFRED H. Died Nov. 22, 1924.
BROWN, AMOS P. Died Oct. 9, 1917.
BUCKLEY, ERNEST R. Died Jan. 19, 1912.
CAIRNES, D. D. Died June 14, 1917.
*CALVIN, SAMUEL. Died April 17, 1911.
CARPENTER, FRANK R. Died April 1, 1910.
CASTILLO, ANTONIO DEL. Died Oct. 28, 1895.
*CHAMBERLIN, T. C. Died Nov. 14, 1928.
CHAPIN, J. H. Died March 14, 1892.
CLARK, WILLIAM B. Died July 27, 1917.
CLARKE, JOHN MASON. Died May 29, 1925.
*CLAYPOLE, EDWARD W. Died Aug. 17, 1901.
*COMSTOCK, THEO. B. Died July 26, 1915.
COOK, GEORGE H. Died Sept. 22, 1889.
*COPE, EDWARD D. Died April 12, 1897.
COX, GEORGE H. Died August 20, 1922.
CROOK, ALJA R. Died May 30, 1930.
*CROSBY, WILLIAM O. Died Dec. 31, 1925.
*CUSHING, H. P. Died April 14, 1921.
*DANA, JAMES D. Died April 14, 1895.
DAVIS, CHARLES A. Died April 9, 1916.
DAWSON, GEORGE M. Died March 2, 1901.
DAWSON, SIR J. WM. Died Nov. 19, 1899.
DAY, DAVID T. Died April 15, 1925.
DEAN, BASHFORD. Died Dec. 7, 1928.
DERBY, ORVILLE A. Died Nov. 27, 1915.
*DILLER, J. S. Died Nov. 13, 1928.
D'INVILLIERS, EDWARD. Died Jan. 4, 1928.
DRYSDALE, CHAS. W. Died July 10, 1917.
*DUMBLE, EDWIN T. Died Jan. 26, 1927.
DUTTON, CLARENCE E. Died Jan. 4, 1912.
*DWIGHT, WM. B. Died Aug. 29, 1906.
EASTMAN, CHAS. R. Died Sept. 27, 1918.
*ELDRIDGE, GEORGE H. Died June 29, 1905.
*EMMONS, SAMUEL F. Died March 28, 1911.
FISHER, CASSIUS ASA. Died Nov. 4, 1930.
FONTAINE, WM. M. Died April 30, 1913.
*FOOTE, ALBERT E. Died Oct. 10, 1895.
*FRAZER, PERSIFOR. Died April 7, 1909.
*FULLER, HOMER T. Died Aug. 14, 1908.
*GILBERT, GROVE K. Died May 1, 1918.
GIROUX, N. J. Died Nov. 30, 1891.
GRASTY, JOHN S. Died June 2, 1930.
HAGUE, ARNOLD. Died May 14, 1917.
*HALL, CHRISTOPHER W. Died May 10, 1911.
*HALL, JAMES. Died August 7, 1898.
HARRISON, SIR J. B. Died Feb. 8, 1926.
HATCHER, JOHN B. Died July 3, 1904
HAY, OLIVER P. Died Nov. 2, 1930.
*HAY, ROBERT. Died December 14, 1895.
*HEILPRIN, ANGELO. Died July 17, 1907.
HICE, RICHARD R. Died March 27, 1925.
HIGGINS, DANIEL F. Died March 21, 1930.
HILGARD, EUGENE W. Died Jan. 8, 1916.
HILL, FRANK A. Died July 13, 1915.
HILLS, RICHARD C. Died Aug. 14, 1923.
*HITCHCOCK, CHAS. H. Died Nov. 7, 1919.
*HOLBROOK, LEVI. Died July 26, 1922.
*HOLMES, JOSEPH A. Died July 13, 1915.
*HONEYMAN, DAVID. Died Oct. 17, 1889.
*HOVEY, EDMUND O. Died Sept. 27, 1924.
*HOVEY, HORACE C. Died July 27, 1914.
*HOWELL, EDWIN E. Died April 16, 1911.
HUNT, THOMAS S. Died Feb. 12, 1892.
*HYATT, ALPHEUS. Died Jan. 15, 1902.
IDDINGS, J. P. Died Sept. 8, 1920.
IRVING, JOHN D. Died July 26, 1918.
JACKSON, THOMAS M. Died Feb. 3, 1912.
*JAMES, JOSEPH F. Died March 29, 1897.
JULIEN, ALEXIS A. Died May 7, 1919.
KATZ, FRANK J. Died Aug. 21, 1930.
*KEMP, JAMES F. Died Nov. 17, 1926.
KENNEDY, WILLIAM. Died Feb. 23, 1926.
KNIGHT, WILBUR C. Died July 28, 1903.
KNOWLTON, FRANK H. Died Nov. 22, 1926.
LACOE, RALPH D. Died Feb. 5, 1901.
LAFLAMME, J. C. K. Died July 6, 1910.
LAMBE, L. M. Died March 12, 1919.
LANGDON, DANIEL W. Died June 21, 1909.
*LE CONTE, JOSEPH. Died July 6, 1901.
LEE, WILLIS T. Died June 17, 1926.
*LESLEY, J. PETER. Died June 2, 1903.
LIBBEY, WILLIAM. Died Sept. 6, 1927.
LOUGHRIDGE, ROBT. H. Died July 1, 1917.
MCCALLEY, HENRY. Died Nov. 20, 1904.
*MCGEE, W J Died Sept. 4, 1912.
MCINNES, WILLIAM. Died March 10, 1925.
MCKELLAR, PETER. Died Oct. 29, 1929.
MARCY, OLIVER. Died March 19, 1899.
MARSH, OTHNIEL C. Died March 18, 1899.
MATTHEW, W. D. Died Sept. 24, 1930.
MELL, P. H. Died October 12, 1918.
*MERRILL, FRED. J. H. Died Nov. 29, 1916.
MERRILL, GEORGE P. Died Aug. 15, 1929.
MILLER, ARTHUR M. Died Oct. 28, 1929.
MILLER, WILLET G. Died Feb. 4, 1925.
MILLS, JAMES E. Died July 25, 1901.

*Nason, Frank L. Died Sept. 12, 1928.
*Nason, Henry B. Died Jan. 17, 1895.
*Neff, Peter. Died May 11, 1903.
*Newberry, John S. Died Dec. 7, 1892.
Newsom, John F. Died Oct., 1928.
Niles, William H. Died Sept. 12, 1910.
Norwood, Chas. J. Died Jan. 20, 1927.
*Orton, Edward. Died Oct. 16, 1899.
*Osborn, Amos O. Died March, 1911.
*Owen, Richard. Died March 24, 1890.
Patton, Horace B. Died July 16, 1929.
Peck, Frederick B. Died Nov. 2, 1925.
Penfield, Samuel L. Died Aug. 14, 1906.
Penhallow, David P. Died Oct. 20, 1910.
Pettee, William H. Died May 26, 1904.
*Platt, Franklin. Died July 24, 1900.
Pirsson, L. V. Died Dec. 8, 1919.
*Powell, John W. Died Sept. 23, 1902.
*Prosser, Chas. S. Died Sept. 11, 1916.
*Pumpelly, Raphael. Died August, 1923.
Purdue, A. H. Died Dec. 12, 1917.
Rice, William North. Died Nov. 13, 1928.
Robinson, Henry H. Died Oct. 20, 1925.
Rogers, G. S. Died Nov. 18, 1919.
*Russell, Israel C. Died May 1, 1906.
*Safford, James M. Died July 3, 1907.
Saint John, O. H. Died July 17, 1921.
*Salisbury, Rollin D. Died Aug. 15, 1922.
*Schaeffer, Charles. Died Nov. 23, 1903.
Seely, H. M. Died May 4, 1917.
Seña, J. C. da Costa. Died June 20, 1919.
*Shaler, Nathaniel S. Died Apr. 10, 1906.
Siebenthal, C. E. Died March 1, 1930.
Sloan, Earle. Died Aug., 1926.
*Smith, Eugene A. Died Sept. 7, 1927.
*Smock, John C. Died April 21, 1926.
*Spencer, J. W. Died October 9, 1921.
Springer, Frank. Died Sept. 22, 1927.
*Stevenson, John J. Died Aug. 10, 1924.
Sutton, William J. Died May 9, 1915.
Tarr, Ralph S. Died March 21, 1912.
Tight, William G. Died Jan. 15, 1910.
Tilton, John L. Died Nov. 17, 1930.
Thomas, Abram O. Died Jan. 13, 1931.
*Todd, James E. Died October 29, 1922.
Twitchell, M. W. Died Apr. 3, 1927.
Uglow, William L. Died Aug. 3, 1926.
*Van Hise, C. R. Died Nov. 19, 1918.
Van Ingen, Gilbert. Died July 7, 1925.
*Vogdes, Anthony W. Died Feb. 8, 1923.
Wachsmuth, Chas. Died Feb. 7, 1896.
Wadsworth, M. E. Died April 21, 1921.
*Walcott, Chas D. Died Feb. 9, 1927.
Watson, Thomas L. Died Nov. 10, 1924.
Weller, Stuart. Died Aug. 5, 1927.
Weston, Thomas C. Died July 20, 1910.
*White, Israel C. Died Nov. 25, 1927.
White, Theodore G. Died July 7, 1901.
*Whitfield, Robt. P. Died April 6. 1910.
Wilder, Frank A. Died March 8, 1930.
*Williams, George H. Died July 12, 1894.
*Williams, J. Francis. Died Nov. 9, 1891.
*Williams, H. S. Died July 31, 1918.
Wilmott, Arthur B. Died May 8, 1914.
*Winchell, Alex. Died Feb. 19, 1891.
*Winchell, H. V. Died July 28, 1923.
*Winchell, Newton H. Died May 1, 1914.
Woodward, Robt. S. Died June 29, 1924.
Woodworth, Jay B. Died Aug. 4, 1925.
Wright, Albert A. Died April 2, 1905.
*Wright, G. F. Died April 20, 1921.
Yeates, William S. Died Feb. 19, 1908.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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RALPH W. CHANEY, *Secretary*

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Sessions of February 20, 21, and 22

The twenty-ninth annual meeting of the Cordilleran Section of the Geological Society of America was held at Berkeley, California, on Thursday, Friday and Saturday, February 20, 21 and 22, 1930.

Election of officers

A business meeting and luncheon was held at the Faculty Club, with 18 Fellows of the Society in attendance. A nominating committee appointed by the Chairman, Dr. T. Wayland Vaughan, proposed the following officers for the year 1931:

Chairman, John P. Buwalda
Secretary, Ralph W. Chaney
Councilor, William D. Matthew

Due to the death of Dr. Matthew, the name of T. Wayland Vaughan was substituted for Councilor.

The nominees were subsequently elected in a mail ballot conducted by the Secretary.

Titles and abstracts of papers

The first session of the meetings was called to order by Chairman T. Wayland Vaughan at 2 p. m. on February 20. Sessions were held on the mornings and afternoons of February 21 and 22.

The following papers were presented in the order indicated:

Geology of a portion of the Santa Ana Mountains, Orange County, California

by Bernard N. Moore[1]

(*Abstract*)

The area studied lies on the southwestern slope of the Santa Ana Mountains in the southeastern quarter of the Corona Quadrangle.

[1] Introduced by J. P. Buwalda.

The oldest rocks are a series of slates and sandstones with some lenses of limestone and intruded by andesite dikes. Unconformably overlying the slates is a coarse conglomerate and in part of the area a series of basic lavas and tuffs. All these rocks have been metamorphosed by andesite, granodiorite, and diorite intrusions. Triassic fossils have been reported from the slates. The rocks overlying the "basement complex" constitute a westward dipping homocline, including upper Cretaceous, Paleocene, and Middle Eocene formations, the Vaqueros and Topanga formations, the Puente shale, and Capistrano formation, each of which is bounded by an unconformity or disconformity.

The structure is unusual in that, while the sediments are those typical of the Coast Ranges, the mountains are a tilted fault block, uplift taking place along the Elsinore fault system. The detailed structure consists of a few folds and faults not aligned with the Elsinore system.

The physiographic history shows a long series of repeated uplifts. Some of the lower terraces are marine. In the evolution of the present topography the resistance of the rocks has played a large part.

This paper was read by title.

MOST ANCIENT FORMATIONS IN THE KLAMATH MOUNTAINS

BY NORMAN E. A. HINDS[1]

(*Abstract*)

The oldest complexes of the southern Klamath occupy the western portion of this mountain belt. Four formations are described, but others may be isolated in the little known country west of the Weaverville Quadrangle:

1. Abrams formation.

The most ancient terrane in this region is the Abrams formation which consists chiefly of metasedimentary mica schist and quartz mica schist. Other types of schist, quartzite, and crystalline limestone are interbedded with the dominant types. Concordant and discordant bodies of hornblende schist also are present. Some of the concordant bodies may represent buried flows, but it is believed that most and possibly all are intrusive phases of the succeeding Salmon eruptives.

2. Salmon formation. Separated from the Abrams by an erosional unconformity is a thick series of hornblende schist of various types with occasional interbeds of quartz mica and mica schist, quartzite, and crystalline limestone. The formation apparently represents a highly metamorphosed assemblage of basic flows of the plateau type; local deposits of pyroclastics doubtless were present. Interruptions in the volcanic cycle are indicated by the presence of the sedimentary interbeds.

The age of these two formations is unknown, but comparison with the oldest dated formations in adjacent regions suggests that they are pre-Silurian.

3. Chanchelulla formation. Lying unconformably over the Abrams and Salmon beds is a very thick formation composed at the base chiefly of thinly and thickly bedded cherts, now recrystallized to quartzite, and subordinate

[1] Introduced by W. D. Matthew.

graphitic and micaceous schists, conglomerate, quartzite, and crystalline limestone. At the top of the formation the proportion of chert is somewhat less. Great numbers of sills and dikes of basic igneous rock, now altered to greenstone and greenstone schist, were intruded into the formation. These strata appear to underlie rocks correlated with the Copley metaandesite which in turn is unconformably beneath the Middle Devonian Kennett formation in the Redding Quadrangle. The name Chanchelulla is suggested for the formation because of its wide exposure on and near Chanchelulla Peak in the northeast corner of the Red Bluff Quadrangle.

4. Copley metaandesite. This formation is composed of basic flows and local pyroclastic deposits which have been metamorphosed to greenstone and locally to greenstone schist. The formation is a thick series of plateau pyroxene andesites and basalts, and, from the widely scattered exposures in the southern Klamath, apparently had a wide extent. The Copley is pre-middle Devonian, but its exact age is unknown. Sedimentary interbeds have not been recognized.

5. Intrusive bodies, chiefly of dioritic and andesitic composition, cut these old strata; they are apparently pre-Sierra Nevadan, but their age is unknown.

Discussion by Messrs. H. W. Turner and A. C. Lawson.

INVESTIGATIONS OF GEOLOGICAL SIGNIFICANCE AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY

BY T. WAYLAND VAUGHAN

(*Abstract*)

There are being conducted at the Scripps Institution several kinds of investigations that should yield results of value to geologists. Some of them are as follows:

1. *An investigation of the physico-chemical conditions under which $CaCO_3$ may be precipitated in sea-water.* It has been ascertained that the equations of Johnston and Williamson do not in their entirety apply to sea-water. Precipitation does not occur when it might be expected. This state is probably due to unionized Ca and phosphate, as Sendroy and Hastings found to be the case with blood. A series of controlled experiments are being made and the results observed in the hope that empirical information may be obtained on what happens in the sea. These investigations have been conducted by Messrs. E. G. Moberg, A. H. Gee, and D. M. Greenberg, and are being continued by the first two of the trio. I am informed that a Russian, Andrusov, has made similar experiments and obtained similar results.

2. *Ecological relations of foraminifera and the quantitative part they play in the formation of marine bottom deposits.* R. D. Norton has recently published as Technical Bulletin No. 9 of the Institution a paper entitled "Ecological Relations of Some Foraminifera." This is a study of the depth and temperature relations of about 550 species of foraminifera from the beach line to a depth of 2,849 fathoms in the southwestern part of the North Atlantic, the Mexican Gulf, and Caribbean regions. E. M. Thorp has made estimates of the numbers of individuals of different species of foraminifera in a series of deep sea samples collected between New London, Connecticut, and the Panama Canal Zone. G.

Leslie Whipple is engaged on a study of the foraminifera associated with the marine bottom deposits between Point Concepción and Panama. The three sets of studies by Messrs. Norton, Whipple, and Thorp supplement each other and are of value to geologists in that they will aid in improving the basis for inferring the physico-chemical conditions under which sedimentary rocks were deposited.

3. *Larger foraminifera.* G. L. Whipple has prepared reports on larger foraminifera from the Miocene of Vitilevu, the Eocene of Eua, and the Quaternary of Vavau, to aid J. E. Hoffmeister and H. S. Ladd in their studies of the conditions under which the coral reefs of those islands have been formed. T. W. Vaughan is continuing his studies of the larger foraminifera, fossil and recent, of tropical and subtropical America.

4. *Marine bottom deposits.* E. M. Thorp has nearly ready for press a paper already mentioned and G. L. Whipple is studying the bottom deposits in the eastern Pacific between Santa Barbara and Panama. Other investigations on the large number of samples at the Scripps Institution are contemplated.

5. *Littoral marine erosion.* T. W. Vaughan is making a quantitative investigation of the rates of cliff recession in the vicinity of the Scripps Institution and he is trying to correlate the rates with as many factors as practicable, such as toughness and structure of material and height of cliff. Other factors, such as momentum of waves, shore and near-shore currents, and slope of bottom at and near the beaches, are being considered, but the phenomena are very complex and difficult to handle. G. L. Whipple is assisting with the field and laboratory work. G. F. McEwen is helping with the study of water movements and the intricate mechanics. Because of its bearing on this problem, a detailed chart, scale 1 to 10,000, of the sea bottom off the sea front of the Scripps Institution's property, made in cooperation between the Coast and Geodetic Survey and the Scripps Institution, is mentioned.

Besides the investigations above listed, it is probable that the results of some of the other researches in the ecology and physiology of marine organisms will be of significance in the interpretation of the sedimentary record. One of these is a study by Professor W. R. Coe of Yale University, of the organisms that attached themselves to blocks suspended from the Institution's pier and allowed to remain suspended during definite times.

Other researches might be mentioned, but the notes given are sufficient to show that the results of several lines of research at the Scripps Institution should be useful in the solution of geological problems.

Discussion by Messrs. A. C. Lawson, F. M. Anderson, J. P. Buwalda, J C. Jones, and N. L. Taliaferro.

FRAZIER MOUNTAIN: A CRYSTALLINE OVERTHRUST SLAB WITHOUT ROOTS, WEST OF TEJON PASS, SOUTHERN CALIFORNIA

BY J. P. BUWALDA, C. L. GAZIN, AND J. C. SUTHERLAND

(*Abstract*)

In the progress of the mapping of the Téjon Quadrangle a unique structural feature was encountered by the California Institute summer field class.

Frazier Mountain, stretching westward from Téjon Pass, has an altitude of over 8,000 feet, and with bold faces on all sides rises from 2,000 to 4,000 feet above the surrounding country. It is strikingly flat-topped. The mountain is made of pre-Cretaceous crystalline rocks, mainly gneiss, schist, and intrusives. The San Andreas fault bounds it on the north.

Thick continental sedimentary formations, folded and faulted, of Miocene and probably Pliocene age, border the mountain on the northwest, west, south, and east. The contact between the crystalline rocks above and the sedimentary formations below practically parallels the contours but rises gradually from the 5,000-foot contour at the eastern end of the mountain to the 6,000-foot contour at the western end. This trace indicates a nearly horizontal overthrust, an inference which is verified by exposures of the flat thrust surface at certain points in bluffs on the south and west faces of the mountain. Further, a narrow tongue of gneiss, overlying Tertiary sediments, reaches southward from the south face for about one mile. It indicates notable recession of adjoining parts of the margin of the overthrust mass, presumably by sapping of the weak strata.

Frazier Mountain is a slab of crystalline rocks about 8 miles in east-west length, over 4 miles in width, and about one-half mile in thickness. Like certain peaks in the Alps, it is a mountain without roots.

A minimum measure of the distance through which the mass has ridden forward is its width of something over 4 miles.

While the origin and mechanics of development of this overthrust slab are not yet fully understood, it is presumably not a coincidence that it lies in the concavity of one of the most acute curves of the San Andreas fault.

This paper was discussed by Messrs. C. E. Weaver and E. Blackwelder.

GEOLOGICAL CONDITIONS AT THE LAFAYETTE DAM

BY GEORGE D. LOUDERBACK

(*Abstract*)

An earth embankment, built on a deep natural fill of alluvium, when nearly completed and at a height of 120 feet, sagged down about 22 feet at its crest, spreading out chiefly down stream and raising a ridge of alluvium beyond the toe of the dam about 19 feet high. A series of test borings and pits were put down to determine the nature of deformation within the dam and in the foundation. While the surface expression showed cracks and scarps simulating faulting, it was found that these cracks closed up at moderate depth and that the deeper parts of the dam and the alluvium had been deformed plastically. In the dam, this resulted in a profile of equilibrium for the clay core with lower than the original slopes. The deformation in the alluvium was confined to shallow layers which suffered a plastic displacement, the lateral movement down stream resulting in an up-welling in the form of a ridge. The deeper layers of the alluvium showed marked compression resulting in a comparatively symmetrical distribution of local water pressures.

This paper was discussed by Mr. Buwalda.

LANDSLIDE FAMILY AND ITS RELATIONS

BY ELIOT BLACKWELDER

(*Abstract*)

The paper will set forth the intimate relations between landslides and talus on the one hand and glaciers and mud-flows on the other. All of these may be arranged in an intergrading series in which the typical landslide occupies a central position.

Discussion by Messrs. Buwalda, Lawson, Jenkins, Turner, Jones, and T. Wayland Vaughan.

CONCRETIONS AND GEOLOGICAL RESEARCH

BY R. D. REED

(*Abstract*)

A study of the history of geology shows that concretions have inherited the name formerly applied to all "shaped stones"; and furthermore, that the medieval explanation commonly given for the origin of such stones still colors most geological thinking concerned with the origin of concretions. It is also interesting to note that by the time methods had been devised suitable to cope with concretion problems, reputable geologists had begun to abandon the subject as hopeless. That the growth of concretions is actually a phase of one of the most important of geologic processes has been recognized by many eminent modern geologists, however, and is sufficiently obvious to anyone who will reflect on the subject a little. It is suggested that by the methods of colloidal chemistry and of sedimentary petrography, this last important stronghold of medievalism in geology could now be profitably cleaned out.

This paper was read by title.

ANALCITE DIABASE AND RELATED ROCKS IN CALIFORNIA

BY N. L. TALIAFERRO

(*Abstract*)

Sills of analcite diabase are numerous and widely distributed in the Central and Southern Coast Ranges of California; they were intruded into Middle Miocene sediments at moderate depths and prior to the folding of these beds.

These soda-rich rocks are later than the volcanism which reached its maximum early in the Middle Miocene but they are genetically related to the volcanics; they are most numerous in regions where the submarine flows and tuffs, both basaltic and rhyolitic, are thickest.

The sills range from less than 75 to more than 400 feet in thickness; the majority are approximately 200 feet thick.

The analcite is clearly primary, although belonging to a late magmatic stage. Prehnite, which is sometimes present, also appears to be primary. The analcite ranges from less than 2 to more than 30 per cent in the various sills. In

some cases the analcite has partially replaced the plagioclase prior to the final consolidation of the rock while in other cases the analcite occurs as abundant primary interstitial grains. The analcite is commonly altered to natrolite.

Some of the larger sills show effects of gravitational differentiation. These usually have a relatively thin marginal zone of average composition due to rather rapid cooling, with an interior whose upper portion approaches the syenitic in character, grading downward to a rock so rich in augite and olivine as to be almost a peridotite. In this respect they are analogous to the Lugar sill described by G. W. Tyrrell. Many of the sills are cut by contemporaneous dikes and schlieren of analcite-rich rocks, which might be called analcite-syenites, and which seem to be the products of crystallization-differentiation. These represent the residual soda-rich portions of the magma. The sills are almost universally cut by veins of calcite and quartz which may represent the composition of the residual magmatic waters.

The usual minerals present are plagioclase, ranging from albite to basic labradorite, augite, titanaugite, olivine, analcite, natrolite, prehnite, calcite, magnetite, ilmenite, apatite, titanite, chlorite, and serpentine. Aegirite is occasionally present, and barkevikite and biotite occur in one intrusion.

Discussion by Messrs. C. E. Weaver, H. W. Turner, A. C. Lawson, and J. P. Buwalda.

GEOLOGY OF THE LEAD AND ZINC DEPOSITS OF SOUTHWESTERN EUROPE

BY HARRY V. WARREN [1]

(*Abstract*)

Until 1900 southwestern Europe was the leading producer of lead in the world and even today contributes approximately 10 per cent of the world's annual production.

In the past very few investigations of these deposits have been made by economic geologists, most of the work having been done by "practical" miners. As a result, little has been known of the origin, classification and mineral association of the deposits.

This paper outlines the results of two years of investigation, the chief contributions of scientific importance being as follows:

1. The ores are all hypogene in origin.
2. The ores were not deposited in the Paleozoic but in the Early Cenozoic or Late Mesozoic.
3. Freibergite is the only important primary silver-bearing mineral in this area.
4. Dolomitization is frequently associated with ore deposition.
5. Grünerite is associated with lead and zinc sulphides in one Pyreneen deposit.

This paper was read by title.

[1] Introduced by F. L. Ransome.

STUDY OF THE SAN ANDREAS RIFT AND ADJACENT FEATURES NEAR REDLANDS, CALIFORNIA

BY GEORGE A. CUMMINGS [1]

(Abstract)

A short section of the San Andreas rift has been studied in detail, in an attempt to supplement work already done in the vicinity.

In the area the rift follows the southern base of the San Bernardino Mountains. Its course is marked by numerous physiographic features indicative of recent earth displacement. In one case a ravine has been offset abruptly two times in crossing the fault zone.

The fault zone is composed of numerous interlacing faults tending roughly to parallel the master fault. These faults are in general nearly vertical. The dominant movement on them seems to have been horizontal. A feature of the faulting is the occurrence of a narrow strip of Tertiary sediments which can be traced for several miles, bordered on either side by the immensely older gneisses.

The areal geology shows the rift to be bordered on the north by a gneissic complex and two sedimentary formations, the Mint Canyon and the Potato sandstone. The rocks to the south are schists and Quaternary gravels.

This paper was discussed by Mr. A. C. Lawson.

UPPER TRIASSAIC STRATIGRAPHY OF THE HAWTHORNE AND TONOPAH QUADRANGLES, NEVADA

BY SIEMON WM. MULLER [2]

(Abstract)

The Upper Triassic rocks in the Hawthorne and Tonopah quadrangles crop out in a number of mountain ranges west of Big Smoky Valley. Fossils collected by the writer, supplemented by the collection from the National Museum kindly loaned to the writer by Dr. T. W. Stanton, represent several faunal assemblages containing forms of limited vertical range but of wide geographic distribution. A number of species and genera new to North America can be traced to such widely separated regions as Timor, Sicily, and the Alps. The horizons represented by these faunal assemblages are of the Upper Karnic and Noric stages of the Upper Trias.

Discussion by Mr. J. P. Smith.

HORIZONTAL DISPLACEMENT ALONG THE SAN ANDREAS FAULT IN THE CARRIZO PLAIN, CALIFORNIA

BY H. O. WOOD AND J. P. BUWALDA

(Abstract)

With the aid of aerial photographs a field study has been made of the drainage patterns and other physiographic features of a rather exceptional section

[1] Introduced by J. P. Buwalda.
[2] Introduced by Eliot Blackwelder.

of the San Andreas rift in the Elkhorn scarp region on the east side of the Carrizo plain. Offsets in stream courses of different sizes and depths range from about ten feet up to several thousand feet. The evidence indicates clearly that the block west of the fault has moved northward relative to the eastern block at least several thousand feet in very recent time; the drainage courses are very young features. Total horizontal displacement of much greater magnitude, measurable in terms of many miles, or in tens of miles, is thereby strongly intimated.

The interpretation of the drainage patterns as merely subsequent streams is entirely inadequate as the offsets are practically without exception in the same direction.

Discussion by Messrs. B. L. Clark, A. C. Lawson, and F. M. Anderson.

LAVA TREE CASTS AND TREE MOLDS

BY R. H. FINCH [1]

(*Abstract*)

Lava flows frequently produce tree molds, holes in the solidified flow, or casts, projections above the flow surface. The origin of these formations is due simply to chilling of lava when it came into contact with trees. If the lava is quite fluid the elevation of the flow surface after cooling is usually much less than it was during height of flow. The casts of trees, sometimes 20 feet high, bear witness to the height of the lava during the flow. In places where there is but little adjustment of level on cooling, holes in the lava surface show where trees formerly stood. Their formation is so simple and obvious that it is surprising to find involved explanations offered.

This paper was read by title.

TERTIARY DEPOSITS BORDERING THE SIMI VALLEY, CALIFORNIA

BY W. P. WOODRING

(*Abstract*)

The Eocene deposits in the hills bordering the Simi Valley within the limits of the Santa Susana and Calabasas quadrangles have a maximum thickness of almost 8,000 feet and consist of three distinct formations, each of which is further subdivided into several members. Thick conglomerates lie at the base of each formation, but they are discontinuous and at places conglomerates are absent at the base but lie within the formation. No deposits of Téjon Age are recognized in this area.

Soft sandstone having a thickness of 340 feet and carrying *Siphogenerina*, *Valvulineria*, and other foraminifera, the stratigraphic significance of which was pointed out by D. D. Hughes, is of Middle Miocene age. It formerly was mapped with the overlying Modelo formation.

The so-called Saugas formation of this region carries the fauna of the San Diego formation.

[1] Introduced by R. W. Chaney.

DO FAULT PATTERNS INDICATE TYPE OF DISPLACEMENT?

BY RICHARD JOEL RUSSELL[1]

(*Abstract*)

Where notable horizontal offsets have been definitely demonstrated along faults of relatively steep dip the surface traces, or patterns, are straight, or gently curvilinear. In greatest contrast are the complexly sinuous patterns of low angle thrusts. The pattern of most normal faults and high angle thrusts appear to attain intermediate complexity but possibly differ in orientation with respect to the upthrown block. Criteria for recognizing orientation appear to be: (1) The direction of convexity of the pattern of the fault as a whole; (2) The direction of sharp salients between gentle curves in detailed pattern; and (3) The distribution of branch faults. If this thesis be valid it is of particular interest in the Great Basin. The Surprise Valley fault is considered as a practical application.

Discussion by Messrs. A. C. Lawson, J. P. Buwalda, and E. Blackwelder.

MIOCENE BROWN SHALE OF THE KETTLEMAN HILLS WELLS, CALIFORNIA

BY HUBERT G. SCHENCK

(*Abstract*)

On the surface, the siliceous "brown" shale (McLure Shale) rests on Cretaceous, Eocene, Oligocene (?), and Miocene formations, the youngest of which is an Upper Miocene sandstone. It is overlain by the Jacalitos (Lower Pliocene) formation. In the Kettleman Hills wells, the shale varies in thickness from 900 to 2,400 feet and is situated above the Temblor (Middle Miocene) sandstone and below the Jacalitos. The upper part of the shale is richly diatomaceous. In the lower division there are also diatoms, but they are commonly pyritized. Foraminifera are very rare, whereas fish scales and bones are common throughout. Impure collophane is conspicuously present in the lower division. A thin bentonite-like stratum occurs fifty feet above the Temblor sandstone in many of the North Dome wells. Judging from stratigraphic position and fossils, the shale is Upper San Pablo (Upper Miocene) in age, and is not to be correlated with the true Monterey, Lower Maricopa, or Temblor shales, some of which it resembles superficially. Comparisons with other shales having similar stratigraphic positions show that the question of the age of this shale is of more than local significance.

Discussion by Messrs. Bruce Clark, F. M. Anderson, R. D. Reed, and T. Wayland Vaughan.

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[1] Introduced by G. D. Louderback.

AQUEOUS CHILLING OF BASALTIC LAVA ON THE COLUMBIA RIVER PLATEAU

BY RICHARD E. FULLER[1]

(Abstract)

In Washington in the vicinity of Moses Coulee, palagonitic breccias and ellipsoidal lavas occur as the basal phase of numerous flows. The breccias, which range up to 50 feet or more in thickness, contain inclined elongate masses of basalt, which are either slaglike or ellipsoidal. They are invariably coated with a thick selvage of transparent basaltic glass. These inclined masses dip almost uniformly at about thirty degrees. The larger pillows tend to flatten in contact with the normal lower flow. In settling, their surfaces develop remarkable tensional features.

The advance of a very fluid flow into a shallow body of water is considered to have resulted in the granulation of the lava in a manner similar to the quenching of slag. Over this mass the flow would have poured in thin tongues. It would thus build foreset beds of granulated lava and inclined streaks, while the flow would have gradually advanced on this accumulation as if on dry land. The palagonitization of the breccia is attributed to the retention of the steam by the presence of the overlying flow.

The basal phase of some flows is formed almost entirely of ellipsoidal lavas, which may attain a thickness of over a hundred feet. Although the pillows are predominantly horizontal, the exposures show some inclined accumulations of palagonitic breccias, proving a mode of origin similar to that of the foreset bedded type. The formation of the pillows is attributed to the higher viscosity of the advancing lava, permitting it to drop into the water in gigantic globules, which, due to gravity, would settle to a roughly horizontal position. These masses in the course of formation may have been subdivided by the explosive generation of steam.

In the above instances, flows have come in contact with shallow lakes. In Douglas Creek, a tributary to Moses Coulee, a palagonite breccia appears to have been formed by a very fluid lava becoming immersed in a superfluity of water in a lake, which contained Lower Miocene sediments. In this same valley, later flows show the incipient development of ellipsoidal surfaces in contact with moist sediments. This variety of pillow structure is attributed to steam action.

This paper was discussed by Mr. A. C. Lawson.

GEOLOGY OF THE ADELAIDA QUADRANGLE, CALIFORNIA

BY W. LAYTON STANTON, JR.[2]

(Abstract)

This area lies across the southern Santa Lucia Mountains west of Paso Robles.

No old land surfaces exist in this district, the land forms being due to structurally controlled erosion which has progressed to a late mature or old age stage.

[1] Introduced by C. E. Weaver.
[2] Introduced by J. P. Buwalda.

In the quadrangle mapped the sedimentary series, with an aggregate thickness of about 25,000 feet, includes the Franciscan, Knoxville, Chico, Monterey (including Vaqueros beds and Salinas shales), and Paso Robles formations. The igneous rocks include peridotite altered to serpentine, granite, rhyolite, basalt, and diabase. Altered Salinas shale in contact with highly calcitized and silicified serpentine indicates either a post-Monterey age for the intrusive, or changes due to solutions rising through pre-Monterey serpentine.

All structural lines trend northwest-southeast, paralleling the Santa Lucia Range. An important zone of faulting bounds the range on the west. This fault-zone is approximately a mile wide and is composed of several, nearly parallel, normal faults, with little evidence of horizontal movement. In the northern part of the area the general structure is broadly anticlinal; farther south, extensive faulting obscures any generalized folded structure.

Of particular interest in the geology of the region is the contrast in distribution of the formations in the northern and southern portions of the quadrangle. A large section of sedimentary rocks present in the south are absent farther north, presumably because they were not deposited.

The quicksilver deposits, now being actively worked, occur in different formations but are always associated with faults and serpentine. Chromite, asbestos, and important crystalline limestone deposits also occur.

Discussion by Messrs. F. M. Anderson, B. L. Clark, H. G. Schenck, C. E. Weaver, and R. D. Reed.

SYMPOSIUM ON RELATIONSHIPS BETWEEN EOCENE AND OLIGOCENE, OF GREAT VALLEY, CALIFORNIA

The following eight papers are contributions to the symposium subtitled The stratigraphic and faunal relationships between the Eocene and Oligocene of the Great Valley of California; Eliot Blackwelder, leader.

KREYENHAGEN SHALES AND THE LILLIS SHALE

BY FRANK M. ANDERSON

(*Abstract*)

The type locality of the Kreyenhagen shales is on Canoas Creek in the immediate vicinity of the Kreyenhagen oil wells. From this point the zone can be followed east to Big Tar Canyon and farther, and west to Zapata Creek and beyond it. These shales were described as having a thickness of 900 feet at places on this zone. They are overlaid unconformably by the Temblor sandstones that form the main mass of Reef Ridge southeast of Coalinga.

The age of the Kreyenhagen shales was originally given as Eocene, partly on account of their stratigraphic relation to the beds above and below, and partly upon the basis of their foraminiferal and molluscan faunas at the type locality.

The name "Kreyenhagen shales" was also applied to a group of strata of similar lithologic character extending through the hills to the west, northwest and north of Coalinga, which group is clearly of Eocene age as determined by

characteristic fossils. This zone of shales can be followed readily from the vicinity of the old coal mine west of Coalinga, northward, eastward, and northwestward for more than 30 miles. It is underlaid by lignitic and carbonaceous beds at many points along its strike. It is overlaid by fossil-bearing Eocene beds which have been included under the name "Domengine sands" or sandstones.

The exact relation of the Kreyenhagen shales to the Domengine group was not stated, except that it is stratigraphically below the latter, and was said to have "a maximum thickness of 600 feet as exposed in the hills a few miles north of Coalinga."

Overlying the beds included under the name "Domengine sands" there is a much thicker aggregate of hard, white, siliceous strata which are lithologically very different from the Kreyenhagen shales, forming a group some 1,250 feet in thickness which were referred by the author to the Miocene in the original description upon both lithologic and faunal grounds. These beds contain a Miocene fauna.

Other writers have since claimed that this group of strata, which is well exposed in Phœnix Canyon, is the stratigraphic equivalent of the Kreyenhagen shales for the region north of Coalinga. It can be shown, however, that these strata differ from the Kreyenhagen shales of the type locality in many important respects, and occupy a different stratigraphic position with relation to the beds above and below. This group is here designated the Lillis shale, from its occurrence in Cantua Canyon, on the large Lillis Ranch.

In the original discussion, this group of shale was clearly distinguished from the Kreyenhagen by the author in 1905, and it was shown to form a later stratigraphic unit. In a second paper, 1908, it was clearly stated that while stratigraphically and structurally the strata of this group are closely connected with the Eocene, yet in the matter of fauna they are allied more closely with the Miocene. Their lithology is also without any doubt that of the Miocene.

In the light of broader studies of the Miocene stratigraphy of the Coast Ranges the Lillis shale, extending from Coalinga northward for many miles, should take its place in the Miocene sequence.

STRATIGRAPHIC PROBLEM OF THE KREYENHAGEN SHALE, CALIFORNIA

BY OLAF P. JENKINS

(Abstract)

The brown shales and diatomite beds which lie between Eocene and Miocene fossiliferous sandstones, exposed along the western side of the San Joaquin Valley, are known by many geologists as the "Kreyenhagen shale." The distribution, thickness and general character of this shale are described. Detailed stratigraphic sections show graphically the author's correlation from place to place of the various zones in the shale, the relationships of the associated beds, and the positions from which fossil collections have been secured. The exact position of contacts is stressed. The stratigraphic study strongly suggests that the shale series represents a facies of the type Téjon sandstone of the south and the Markley formation of the north. The bed containing the

"Ruckman collection" (Lincoln age) of Domengine canyon, formerly supposed to be part of the Kreyenhagen shale, is shown to overlie unconformably the so-called Kreyenhagen shale as well as to underlie, unconformably, the Temblor sandstone, and is probably equivalent to the Kirker formation of the north as well as the San Emigdeo (San Lorenzo) formation of the south. Furthermore, it is represented west of Wagonwheel Mountain by certain shales and sandstones which lie between the "Kreyenhagen shale" and the Miocene. The economic significance of the whole Kreyenhagen problem is outlined.

STRATIGRAPHIC RELATIONSHIPS IN THE MOUNT DIABLO AREA OF THE UPPER EOCENE DEPOSITS TO THOSE OF THE OLIGOCENE

BY BRUCE L. CLARK

(*Abstract*)

The discovery by Dr. Thomas Bailey of well-preserved Téjon fauna from a series of beds in the Potrero Hills, which beds have a similar lithology and stratigraphic position to those of the Markley formation of the type section north of Mount Diablo, makes it very probable that the age determination of the Markley by B. L. Clark as being Oligocene is incorrect but that it is the equivalent to the Téjon (Upper Eocene) of other parts of the State. The unconformity which was described as coming between the Markley formation and the Kirker is apparently the break between the Eocene and Oligocene of that area.

The invertebrate fauna of the lower beds of the Kirker formation has been correlated with that of the Lincoln horizon of the Oligocene. This correlation is still believed to be correct. This fauna in the Kirker is equivalent to that which was found a number of years ago from the uppermost Kreyenhagen shales north of Coalinga.

This paper was discussed by Messrs. F. M. Anderson and O. P. Jenkins.

EOCENE AGE OF THE MARKLEY FORMATION

BY THOMAS BAILEY[1]

(*Abstract*)

A section from the Potrero Hills north of Suisun Bay will be described and a geological map of that area shown.

The stratigraphic position of a Téjon fauna found in the Markley formation will be discussed as well as the evidence for the correlation of these beds with the type Markley.

This paper was read by Mr. Taliaferro.

[1] Introduced by B. L. Clark.

STRATIGRAPHIC RELATIONS OF THE DOMENGINE AND MARKLEY FORMATIONS IN THE ANTIOCH, VACAVILLE AND NAPA QUADRANGLES

BY CHARLES E. WEAVER

(*Abstract*)

The massive Markley micaceous sandstones with a thickness of nearly 3,000 feet rest in apparent conformity on the massive cross-bedded Domengine sandstones of the Upper Eocene whose thickness in this region averages between 100 and 300 feet. Both formations contain marine molluscan fossils and have been strongly folded and faulted. They outcrop prominently north of the town of Vacaville between the Vaca and Sacramento valleys, in the Potrero Hills, in the hills between Jameson Canyon and Benicia and in the ranges on the south side of Suisun Bay in the southern part of the Antioch Quadrangle. The Markley formation is characterized by intercalations of tuff beds near the base and top.

This paper was discussed by Mr. B. L. Clark.

FORAMINIFERA OF THE LILLIS SHALE

BY C. C. CHURCH [1]

(*Abstract*)

At the well-known locality of the shale in Phœnix Canyon, foraminifera are represented by an abundance of impressions and a few poorly preserved forms, but at two other localities the fossils have been found well preserved. One of these is an old quarry in the northeast one-quarter, section 2, township 1 north, range 1 east, M. D. M., Contra Costa County, California. The assemblage of species collected there is very striking and unlike that from any other known formation in California. The forms show no close relationship with any known Eocene foraminifera of North America. They are likewise quite distinct from any of the faunas which have become so well known from the Temblor Miocene. The affinities of the forms found, however, seem to be with the Miocene rather than the Eocene. No ties have thus far been found, through the use of the foraminifera, to bind the formation to the Oligocene of Europe, the West Indies, or Central America.

The other locality where the same foraminifera have been found preserved is in one of the wells drilled by the Associated Oil Company near the center of the San Joaquin Valley (Herminghaus Well Number 1), section 35, township 13 south, range 16 east, M. D. M. In a brown shale at 4,877-4,885 feet an abundance of the characteristic forms was found. The same formation extended down to 4,973 feet. The underlying formation at this point was Eocene, consisting of gray sands and sandy shales bearing an abundance of very characteristic Eocene foraminifera and mollusca. The cores from the Eocene in this well showed dips of 17 degrees to nearly 30 degrees, while the organic Lillis shales above were never found to dip more than 5 degrees. An angular unconformity is therefore thought to exist between the two formations.

[1] Introduced by B. L. Clark.

Some of the more distinctive genera of foraminifera of the Lillis shale are: *Ahphimorphina, Gyroidina, Lenticulina, Bulimina* and *Robulus.*

Discussion by Messrs. B. L. Clark, O. P. Jenkins, H. G. Schenck, and F. M. Anderson.

SILICOFLAGELLATES FROM THE LILLIS SHALE

BY G. DALLAS HANNA[1]

(Abstract)

The information yielded by the Silicoflagellata is of much value in world wide correlation because of limited number of species, wide geographic range and limited geologic range. The value is increased by the pelagic habit of the animals when alive. The Lillis shale contains eight species, all common. Only two of these extend upward to the Monterey while several of the most characteristic of them have been listed from the organic deposit on Barbados Island and the diatom deposits of Jutland, Denmark. The latest age determination of the first is Lower Miocene while the latter has been referred to the Eocene. This conflict of data is confusing and leads to the supposition that something may be wrong with one or the other age assignment. All of which demonstrates that by means of the diatoms, silicoflagellates, foraminifera and radiolaria we should be able to correlate the Lillis shale definitely with European and other formations of the world on the basis of identity of species. A correct age assignment must therefore entail a careful scrutiny of foreign literature pertaining to these other formations.

DIATOMS FROM THE LILLIS SHALE

BY G. DALLAS HANNA[2]

(Abstract)

In 1927, 52 species of diatoms were listed from this formation, mostly from Phœnix Canyon, near Coalinga. An attempt was made at that time to confirm the previously formed idea that this was not the Kreyenhagen shale of the original definition. The age was held in doubt but was thought to be Lower Miocene. Further study of these fossils from this shale, together with information gained from detailed studies of the diatoms of the Temblor and Monterey shales has disclosed some relationship to these Miocene formations but this is not sufficiently close to permit a positive age assignment, even yet. It may be said with an assurance bordering on certainty that the diatoms show the Lillis shale to be equivalent in time to the celebrated deposit on Barbados Island in the West Indies. Unfortunately the age of this latter is clouded with some doubt but the latest determination (by Nuttall) places it equal to the Naparima clays of Trinidad which were definitely placed in Lower Miocene.

[1] Introduced by B. L. Clark.
[2] Introduced by B. L. Clark.

The two preceding papers were presented together by the author.

Discussion by Messrs. B. L. Clark, T. W. Vaughan, F. M. Anderson, and H. G. Schenck.

The presentation of abstracts was resumed.

SUBSEQUENT FAULTING IN THE GREAT BASIN

BY CARLTON D. HULIN

(Abstract)

A *subsequent fault* is defined as any fault whose detailed location has been predominantly determined by previously existing (pre-faulting) planes of weakness. Such planes of weakness may consist of joint planes, joint systems or previously existing fissure systems. These planes of weakness may and commonly do differ in strike from the mean strike of the faults the details of whose course they have determined. As a result subsequent faults commonly follow a zig-zag course, the elements of which consist of portions of two or more fissure or joint systems.

The Benton Range, lying in eastern Mono County, California, may be taken as the type locality for subsequent faults. The Benton Range, trending north and south, is a typical "Basin Range" tilted fault-block mountain. The east slope, a tilted old-age erosion surface locally mantled with bedded tuffs and a thin basalt flow, has been only slightly dissected since tilting. The west slope in contrast is a rugged fault escarpment 500 to 1,000 feet high. In detail this escarpment results from major displacement along a fault line following a zig-zag course.

The elements of this zig-zag line of major displacement when continued mark fault lines of minor vertical displacement—10 to 50 feet. Manifestly the zig-zag line of major displacement is composed of elements of previously existing intersecting joints of fissures of two or more systems.

The great fault escarpment of the Inyo Range, the Sierra Nevada, the Panamints, and of the Wassuk Range in detail are marked by zig-zag fronts which are held to result from major subsequent faults.

Subsequent faults composed of elements striking oblique to the trend of the ranges are held to be abundant in the Great Basin. Uplift of "Basin Ranges" along faults of this type accounts for the notable dearth of visible faults known to parallel the bases of "Basin Range" mountains.

ICE AS A ROCK

BY ELIOT BLACKWELDER

(Abstract)

Ice has been too largely the concern of the physiographer. It deserves more study from the petrologist and especially the structural geologist. In many respects it is the most interesting and informative rock available for structural study. Rock deformation may be investigated in glaciers more easily than

almost anywhere else. Ice is also unique in being at the same time an igneous, sedimentary and a metamorphic rock, and in passing somewhat readily from one category to the other.

This paper was discussed by Mr. Rogers.

THE PEACOCK RANGE, ARIZONA

BY W. M. DAVIS

(*Abstract*)

The Peacock Range in northwestern Arizona is an east-tilted fault-block of massive granite, so maturely dissected that no trace of a fault-plane is seen along the base of its western front where a detrital bahada descends to a broad intermont plain, and that no trace of a pre-faulting "Powell surface" of low relief is preserved on its black (eastern) slope except where a few little lava-capped spur ends dip under a narrow aggraded trough. Near by on the east is Truxton mesa, an evenly uplifted, lava-capped granitic mass through which a canyon clearly reveals the slightly uneven Powell lowland to which the granite had there also been degraded before the lava sheets were poured out upon it. Farther east still a retrograded fault-scarp rises strongly to the Arizona plateau of nearly horizontal Paleozoic strata. The Peacock Range teaches the important lesson that the invisibility of the fault-scarp along the frontal base of a Basin Range and of the Powell surface on its back slope by reason of well-advanced erosion, does not in the least contradict the fault-block origin of the range, but merely makes that origin less manifest. In this case the demonstration of such origin is provided by the relatively even surface of the granite under the lava-capped spur ends of the back slope, taken in connection with the much larger area of the same worn-down surface in Truxton mesa.

This paper was read by title.

ORIGIN OF CAVERNS

BY W. M. DAVIS AND CECIL KILLINGSWORTH

(*Abstract*)

Current theories for the origin of limestone caverns provide no adequate reason for the reversal of processes involved in cavern excavation by solution and in cavern replenishment by dripstone deposition. It is here proposed to explain this reversal first by ascribing solutional excavation to an earlier time when the cavern region stood so low that the cavern rock was below the local water table and therefore permeated with ground water; and next, by ascribing depositional replacement to a later time when, in consequence of regional elevation, the excavated cavern was raised above the water table.

Some solution of calcite undoubtedly takes place in carbonated ground water as it descends through limestone crevices toward the water table: but as soon

as the cavities thus excavated become large enough to be partly filled with ground air, allowing the escape of CO_2, a replenishing deposition of calcite in the form of dripstones is more probable than a continuation of solutional excavation. But below the water table, no such escape of CO_2 is possible; and even if descending ground water becomes saturated with calcite before reaching the water table (which need not always be the case), it will, as it sinks below the water table, gain increased solvent power by reason of increasing pressure. Thus conditioned its water-logged paths of movement may be slowly dissolved out and enlarged to cavernous size at considerable depths.

If the return of deep-lying ground water to the water-table level involves a considerable ascent with a correspondingly great decrease of pressure, it may become saturated before reaching the water table; and it should then deposit calcite crystals on the walls of the passages or cavities through which it ascends. The crystal-lined caverns of Missouri may perhaps be thus explained. In general an ascensional movement of ground water may cause deposition of vein minerals, but such deposition is not to be expected in descending ground water. At any stage of solutional excavation below the water table, regional elevation may take place; and when the caverns are thereupon emptied of their ground water, their occupation by ground air will promote a change from excavation to replenishment.

The time element is held to be important in subwater-table solution; for the limestone of most caverns has spent by far the greater part of its existence below the water table. We have found no means of proving the process here proposed for cavern origin but believe it to be worthy of further consideration. To our regret we have not been able to examine European literature on the question.

This paper was read by title.

ELEVATED SHORELINES OF THE SANTA MONICA MOUNTAINS, CALIFORNIA

BY W. M. DAVIS, W. C. PUTNAM, AND G. L. RICHARDS

(Abstract)

The Santa Monica Mountains extend 50 miles westward from Los Angeles and end in the Pacific Ocean. The western two-thirds of their southern side, fronting the sea, has been cliffed at three levels by marine abrasion. The eastern third is adjoined by the south-sloping and submaturely dissected Beverly plain, formed of mountain detritus and from 500 to 750 feet in height at the mountain margin. The shoreline of the first-cut and now most elevated sea-cliffs, the Malibu cliffs, is not seen at the west end of the range, but it soon appears and, with gradual eastward ascent, reaches a height of about 500 feet at the beginning of the Beverly plain. The second or Dumé shoreline must be below present sealevel at the west end of the range, but it appears some 12 miles eastward and slowly rises to about 300 feet at the beginning of the Beverly plain; its cliffs exhibit sections of the deformed strata of the mountain mass, evenly truncated by the abraded offshore platform of the Malibu shoreline, which is thinly overlaid with gravels under a heavier cover of subaerial

detritus washed out from the Malibu cliffs and from the valleys which interrupted them. The recession of the Dumé shoreline was detained at mid-length of the coast by a ledge of resistant igneous rock; there its low cliffs advance in an acute salient a mile seaward of the more nearly rectilinear Malibu shoreline; but farther eastward its recession was so great that at certain points it appears to have undercut and destroyed the Malibu shoreline. The present or Monica shoreline has a larger salient at Dumé point; thereabouts and farther eastward its cliffs undercut the eastward rising Dumé platform and its detrital cover. The two earlier shorelines appear to have continued eastward along the southern slope of the mountains; but the Monica shoreline, turning southward, departs from them and cliffs the Beverly plain. The contrast of this plain with the lowlying Oxnard plain northwest of the mountains is striking.

This paper was read by title.

SYNTHETIC SULPHIDE REPLACEMENT OF ORE MINERALS

BY J. C. RAY [1]

(*Abstract*)

The paper is a preliminary report on synthetic sulphide replacement of natural sulphide minerals and aqueous solutions at temperatures below 100°C.

Discussion by Mr. A. C. Lawson.

OPAL STALACTITES FROM A LAVA TUBE IN NORTHERN CALIFORNIA

BY CHARLES A. ANDERSON [2]

(*Abstract*)

Small stalactites of opal occur in a lava tube 20 miles northeast of Red Bluff, California. The stalactites and a few associated stalagmites appear to have been formed by the evaporation of silica-bearing water dripping into the tube.

This paper was discussed by Messrs. A. S. Eagle and A. F. Rogers.

PETROLOGY OF THE CALCAREOUS BEDS OF SAN PEDRO HILLS, CALIFORNIA

BY R. D. REED

(*Abstract*)

The calcareous beds of San Pedro occur in several isolated outcrops, and have been cored in at least one deep well. Although the last word has not yet been said on their correlation, they may reasonably be taken as belonging to the same general period, probably an interglacial period. They consist of

[1] Introduced by Eliot Blackwelder.
[2] Introduced by A. C. Lawson.

several lithologic types, all high in the remains of calcareous organisms, and several much like chalk in general appearance.

The detrital constituents have a wide range in size, but all appear to be derived from a "western" source, probably the Miocene and Pliocene strata of San Pedro Hill. Among the organic constituents, foraminifera hold first place in most samples. The species represented most abundantly vary from place to place and from bed to bed. Other organisms well represented in some of the beds are calcareous algae, bryozoa, echinoids, and mollusks. The amount of very fine material has a great range in quantity and character.

The constitution of these beds suggests that they were deposited in clear water, under the influence of currents that were strong at times, and that the basin of deposition was open to the sea. The depth of the water must have been something like 10 or 20 fathoms. The temperature, as shown by a study of the mollusks, was considerably warmer than that now prevailing in the same latitude.

It is concluded that at the time these beds were deposited, San Pedro Hill was a low island, separated from the mainland, which may have been of low relief, by a sea over what is now the Los Angeles Basin. Sediment from the mainland was thus prevented from contaminating the calcareous deposits.

The great abundance of calcareous concretions and lenses in the Miocene rocks of San Pedro Island may have assisted in furnishing appropriate conditions for the growth of calcareous organisms in such extreme abundance.

The conditions inferred to account for the deposition of the San Pedro beds will be compared with those that have been deduced from studies of several similar occurrences in other parts of the world. The conclusion reached is that these beds constitute a fine example of what French geologists call the "facies zoogène."

Discussion by Messrs. E. Blackwelder and A. C. Lawson.

RECRYSTALLIZATION OF XENOLITHS AT CORNUCOPIA, OREGON

BY G. E. GOODSPEED[1]

(Abstract)

Near Cornucopia, in the northeastern part of Oregon, the contacts of Mesozoic granitic intrusives are well exposed. These intrusives, which are mainly granodiorite, have invaded schists and greenstones of Triassic age.

Most irregular contacts prevail. Many apophyses of the granitic mass penetrate upward into the roof rocks in tongue-like projections; and many jagged wedge-shaped blocks of the roof rocks extend downwards for hundreds of feet.

Contact breccias are especially numerous in association with these roof pendants. Their fragments are of various shapes and sizes from an inch or less to several feet in diameter. Most of the xenoliths show various stages of recrystallization effects. In some there is merely the initiation of metacrystic minerals, some show a partial recrystallization, some a complete recrystallization yet retaining an outline of the fragment. Other cases indicate a com-

[1] Introduced by C. E. Weaver.

plete incorporation which has resulted in hybridism. One occurrence shows that a porphyry dike apparently owes its origin to the irruption of a hybrid magma.

The recrystallization zones which surround many of the xenoliths consist in part of hornblende crystals with a mesostasis of quartz. Thin sections of some of these reaction rims show that the long bladed hornblende crystals appear to have been formed by the coalescing of smaller grains. The result is that in these zones there is a distinct separation of the ferromagnesian and silicic constituents, whereas well within the zenolith an even distribution obtains.

The source of many quartz veinlets may be traced to the quartzoze portion of these zones. Likewise the source of lamprophyric hornblendic veinlets may be traced to the hornblende-rich portion of the zones.

Field relations and petrographic evidence are such as to suggest that many of the satellitic phases of the granitic mass may be due wholly or in part to hybridism.

DISPERSION OF SEISMIC WAVES OF THE LOVE TYPE AND THE THICKNESS OF THE SURFACE LAYER OF THE EARTH UNDER THE PACIFIC

BY PERRY BYERLY [1]

(Abstract)

Seismograms written at the Berkeley station during a period of eleven years have been studied and data for the dispersion of the first wave of the Love type under the Pacific obtained. If these observations be correlated with wave velocity and used in Love's formula they point to a thickness of some 40 kilometers for the surface layer of the earth under the Pacific. If they be correlated with group velocity they indicate a thickness of some 20 kilometers. The writer considers the former correlation the better.

GEOLOGY OF THE NORTHERN HALF OF THE WHITE MOUNTAIN QUADRANGLE OF CALIFORNIA-NEVADA [2]

BY GEORGE H. ANDERSON [3]

(Abstract)

This paper presents some preliminary results of a study of the geology of the northern White Mountain Quadrangle made during part of the summer of 1929. The author is continuing his studies in greater detail.

In their broadest and simplest aspect, the White Mountains represent a block faulted on the west and northwest and tilted toward the east. The tilting must have taken place at a rapid rate and have continued into very recent times. Differential movement seems to have occurred also within the mountain mass itself, especially along lines parallel to the general trend of the range. Both physiographic and geologic evidence for the faulting are available.

At least two periods of igneous intrusion appear to be represented in the

[1] Introduced by R. W. Chaney.
[2] A preliminary report.
[3] Introduced by J. P. Buwalda.

batholith which makes up the principal portion of the range. Intermediate to basic rocks of an earlier period were intruded by a later magma of more acidic character.

Evidence for not less than two widely separated periods of volcanic activity is abundant. The earlier effusive rocks, which seem to antedate the intrusions, were apparently of a generally basic character; those of the later stage, some of which bear the appearance of being extremely recent, are of several kinds, ranging from basalts to highly acidic rhyolites.

This paper was discussed by Mr. H. W. Turner.

PLEISTOCENE LAKES OF THE BASIN RANGE PROVINCE

BY ELIOT BLACKWELDER

(*Abstract*)

That there were many lakes in the isolated basins of the province during the Pleistocene period has long been well known. Evidence now at hand shows that a set of late Pleistocene lakes may be readily differentiated from another set of much older Pleistocene lakes.

It seems probable that the later epoch may be divided into two ages, and it is inherently probable that the early Pleistocene set is also multiple. It has been determined that Lake Bonneville and Greater Mono Lake were contemporaneous with the Wisconsin glacial epoch. Many others were probably of the same age. These lakes are now evidenced by well-preserved shore features as well as by characteristic deposits.

On the other hand, the lakes of the early Pleistocene age have lost all trace of lacustrine topographic forms. Their former presence is shown only by their deposits, now greatly eroded. Their age is determined by the scattered finds of mammal bones and particularly by their physiographic relations. A typical case is the lake beds in the Las Vegas, Nevada, bolson—a basin now incapable of holding a lake because it has been drained by a tributary of the Colorado River. These lake deposits antedate the extensive pediments that were planed across them by stream action, and there are reasons for correlating them tentatively with the second (Sherwin) glacial epoch in the Sierra Nevada.

The Pleistocene lake deposits should not be confused with the Pliocene and Miocene lake deposits that are widely exposed in the Basin Range province but which have in many districts been tilted, folded and strongly faulted as well as greatly eroded. In some cases the separation of the Pleistocene from the Tertiary deposits has not yet been made.

Discussion by Messrs. H. W. Turner, A. C. Lawson, and J C. Jones.

GEOLOGY OF THE SOLEDAD QUADRANGLE, CENTRAL CALIFORNIA

BY F. A. NICKELL[1]

(*Abstract*)

The area studied is located between the towns of Salinas and King City, central California, and includes parts of the Santa Lucia and Gavilan ranges on opposite sides of the Salinas Valley.

[1] Introduced by J. P. Buwalda.

Extensive remnants of an old age surface exist on both the Santa Lucia and Gavilan ranges. The age of this surface is post-Pliocene since the faulting in this area which displaced the surface has also tilted the Paso Robles formation (Upper Pliocene, Lower Pleistocene). Elsewhere the surface bevels Pliocene sediments.

The Salinas Valley in this area is a graben with the greater vertical movement occurring along its western side. To the east of the valley is the slightly dissected old surface of the Gavilan Range sloping toward the southwest, cut on diorite and granite. To the west, on the flanks of the Santa Lucia Range, but separated from the Salinas by a flat-topped ridge of crystalline rocks, Tertiary formations have been folded into a syncline with many minor folds.

The pre-Cretaceous complex is composed of the Sur Series (?) of metamorphics, the Santa Lucia granite and the Santa Lucia quartz diorite. Evidence is presented that the Santa Lucia quartz diorite has intruded and is later than the Santa Lucia granite of the Gavilan Range. Presumably both intrusives cut the Sur series.

Upon the complex were deposited the Lower Miocene Temblor sandstone, (about 2,000 feet); the Middle Miocene Salinas shale (about 7,000 feet); the Upper Miocene Santa Margarita sandstone (1,815 feet); the Upper Pliocene and Lower Pleistocene Paso Robles conglomerate (1,100 feet); and Quaternary fans and valley alluvium (estimated at 1,500 feet).

Faulting occurred during two distinct periods. The earlier faulting, accompanied by the folding of the Salinas shale, took place in post-Upper Miocene, pre-Paso Robles time. The movement is indicated along the Reliz Canyon fault, a branch of the King City fault, and may indicate a first period of movement on the latter fracture. Later, in the Pleistocene, two normal faults and an overthrust from the west developed, and strong movement occurred on the King City fault.

If the surface on the Gavilan Range is projected westward across the valley beneath the alluvium, it is seen that its westward continuation on the Santa Lucia Range has been displaced vertically about 4,000 feet along the King City fault. This movement in Lower Pleistocene time depressed the northern Salinas Valley block and greatly accentuated the structure and the physiography of the basin in which the Paso Robles was deposited.

Discussion by Messrs. A. C. Lawson and R. D. Reed.

GEOLOGICAL SECTION OF THE OCHOCO RANGE AND SILVIES PLATEAU SOUTH OF CANYON CITY, OREGON

BY R. L. LUPHER[1]

(*Abstract*)

The Ochoco Range, a narrow east-west chain of peaks and ridges, rises abruptly south of the upper John Day Valley and beyond the range is a high plateau, which is somewhat dissected and deformed. In 1929 a narrow strip 2 to 4 miles wide and 37 miles long was mapped from Canyon City directly

[1] Introduced by J. P. Buwalda.

south across the range and part of the plateau to the Crow Flat ranger station.

The section shows a remarkable sequence of Tertiary and Quaternary continental formations upon a Mesozoic basement. The Mesozoic rocks consist of three marine series and two sets of intrusives. The Cenozoic rocks comprise fourteen divisions of sediments, lavas, and pyroclastics, and three major intrusives. Structural unconformities and intrusive contacts are numerous throughout.

The Ochoco Range south of Canyon City is composed of a core of Triassic serpentine and late Jurassic intrusives in Triassic marine sediments. Farther south the basement of the plateau is made up of two marine series of Jurassic age. The Tertiary section, which is best exposed on the east and south sides of Silvies Valley, includes probable correlatives of all the formations in the classic John Day section. It is of interest to note that several formations and at least four angular unconformities intervene between close correlative of the Columbia River lava and Mascall formation.

Much of the present plateau surface was formed by a puniceous, acid flow correlated with the Rattlesnake Pliocene, which spread widely over an exceedingly flat erosion surface south of the Ochoco Range. The enclosed basins known as Bear and Silvies valleys are structural downwarps in this plateau surface.

The Mesozoic sediments are highly folded and often overturned, but they are not appreciably metamorphosed. The structure of the Tertiary sequence is relatively simple. However, igneous intrusion and erosion of a series of thin formations showing excessive overlap have greatly complicated the areal pattern. Faulting is inconspicuous except on upper Canyon Creek where some late Tertiary rocks have been dropped into a deep pocket south of Canyon Mountain.

This paper was discussed by Messrs A. C. Lawson and C. E. Goodspeed.

STRUCTURE OF A PORTION OF THE SOUTHEAST QUARTER OF THE TEJON QUADRANGLE, CALIFORNIA

BY THOMAS CLEMENTS[1]

(*Abstract*)

Faulting is the dominant structural feature of this area, with the folding definitely related to the same stresses that caused the faulting. The principal faults are the San Francisquito, an overthrust, and the Bee Canyon, the Clearwater, the Violin Canyon, and the Palomas Canyon, which are all normal. The Castaic Syncline is the major fold in the region.

Discussion by Mr. A. C. Lawson.

[1] Introduced by J. P. Buwalda.

GEOLOGY OF THE CENTRAL PORTION OF THE MOUNT PINOS QUADRANGLE VENTURA AND KERN COUNTIES, SOUTHERN CALIFORNIA

BY LEWIS GAZIN [1]

(*Abstract*)

The area lies principally in the northen portion of Ventura County and includes a small section in the adjacent part of Kern County. The rocks within the area mapped are of pre-Cretaceous, Cretaceous (?), Eocene, Miocene, and Quaternary ages.

The oldest rocks consist of metamorphosed sediments, principally calcareous; diorite and gabbro porphyry; and granitic gneiss and schist. The Cretaceous (?) and Eocene have not been differentiated and only the latter has been definitely recognized, the combined thickness exposed approaching 15,000 feet. The Miocene rocks are predominantly marine west of the Cuyama River, but to the east a very thick section of terrestrial deposits has accumulated, extending into Lockwood Basin, and perhaps farther. These deposits are strikingly colored and give rise to an extensive area of badlands.

The structure of the western part of the area is characterized by numerous folds and occasional faults; both have roughly a north-northwest trend. In the eastern portion or Lockwood Basin the deformation is more acute and faulting has played a larger part. The majority of the structural features in this eastern region strike northeasterly and are of a compressional nature, although normal faulting also occurs. Transverse to the prevalent strike in Lockwood Valley, and at least in part of later origin, is a group of faults which have had dominantly horizontal movement. The San Andreas rift, extending across the northeastern corner of the area, is the major feature in the latter group.

From an economic standpoint this area is of historic interest, as one of the early discoveries of gold in California was made in or near San Guillemo Creek, and the colemanite deposits in Lockwood Valley played an important part in the early borax mining of the State.

GEOLOGICAL HISTORY OF LONE HILL, SANTA CLARA COUNTY, CALIFORNIA

BY AUSTIN F. ROGERS

(*Abstract*)

This little hill is a prominent topographic feature six miles south of San Jose and four miles east of Los Gatos. It is an extrusive dome of rhyolitic vitrophyre with a tuffaceous phase. The geological history is revealed by detailed petrographic examination. The following stages are recognized: (1) Vitrifaction, (2) devitrification, (3) pneumatolytic action, (4) hydrothermal alteration, and (5) weathering. Tridymite formed in the pneumatolytic stage was altered to low quartz in the hydrothermal stage. So-called pseudotridymite (quartz paramorphous after tridymite) is found here and also at two other localties in Santa Clara County.

[1] Introduced by J. P. Buwalda.

AGE OF THE HORSETOWN BEDS OF CALIFORNIA

BY FRANK M. ANDERSON

(*Abstract*)

Recent explorations in the Cretaceous areas of northern California and southern Oregon have disclosed an astonishing inadequacy of our knowledge of the composition and faunas of the great Cretaceous sequence on the Pacific Coast, especially in California. Little has been added to this knowledge during the last 30 years.

For more than 60 years the Horsetown formation has been regarded as constituting the middle portion of the Cretaceous section on this coast, below which was to be found an enormous mass of Cretaceous strata belonging to the same sequence and period.

The stratigraphic estimates of Dr. Diller during the early 90's placed the total thickness of strata assigned to the Cretaceous at 30,000 feet, which aggregate Dr. Stanton divided upon paleontologic grounds into three divisions as follows:

Chico group	4,000 feet
Horsetown group	6,000 feet
Knoxville group	20,000 feet
Total	30,000 feet

The top of the Knoxville was placed at the upper limit of *Aucella*, wherever any species of this genus should be found. In the lowermost beds of the Horsetown immediately above, were noted various Cephalopod and other species which were regarded as characteristic of this horizon, including *Crioceras latum*, *Holcostephanus traski*, *Holcostephanus sp. Lytoceras* (*Gabbioceras*) *batesi* and many others.

No well defined line of demarcation, stratigraphic or faunal, was found between Knoxville and Horsetown groups, although on the whole, the faunas of the two were admittedly very distinct.

The oldest European horizon recognized in the Horsetown was not older than Barremian, although the Knoxville was regarded as older.

In the matter of stratigraphic sequence there is much to be learned. In a section extending from Beegum to Rosewood in southwestern Shasta County more than 40,000 feet of strata are exposed in which no evidence of Knoxville has been found, and in which no great disturbance or duplication of beds was detected.

In the district between old Horsetown and the Middle Fork of the Cottonwood Creek, the Horsetown strata alone have a total thickness of more than 15,000 feet, made up largely of dark sandy shales, within which are several zones of conglomerate, some of which are fossiliferous. Many minor faults and some folds were found at different points.

Five distinct faunal zones are recognizable in this section, which in the European time scale have a range from the Valenginian to the Albian, closing at the top with the Cenomanian of the Chico group.

In the lowest horizon there are two or three species that recall the oldest European Cretaceous, the Berriasian horizon of southern France. Although identity of these with European forms can not be positively claimed, the resemblance is sufficiently close to support the view of an analogous and contemporary fauna.

Far above this horizon numerous species of *Crioceras*, *Ancyloceras* and *Holcostephanus* prove the presence of a Barremian horizon.

Near the top of the Horsetown section is found an Albian horizon with *Douvilleiceras mammillatum*, *Desmoceras planulatum* and *Desmoc. latidorsatum* with which are many additional Albian species.

All of the major horizons of the European Lower Cretaceous can be recognized in the Horsetown group alone, without including any of the *Aucella* bearing strata referred to the Knoxville.

This paper was discussed by Mr. Weaver.

TUNDRA CLIMATE LAND FORMS IN THE UNITED STATES

BY RICHARD JOEL RUSSELL [1]

(*Abstract*)

The land forms of higher Alpine regions have too often been described in terms of erosional and depositional processes familiar at lower elevations with existing, or comparatively recent, glaciation as their characteristic variant. Under climatic conditions of coldness, snowiness, and low evaporation rate the processes of nivation, frosting, and solifluction actually introduce land forms such as nivation depressions, nivation cirques, solifluction slopes, and altiplanation terraces. Though it has been recognized that these, and related features, dominate the subarctic scene, it has not been sufficiently well appreciated that their presence in the high mountainous areas of lesser latitudes is no less striking and their role no less important in the totality of landscape. In fact it appears that these land forms have erroneously been attributed to glacial, or other, processes in many instances.

This paper was not discussed because of lack of time.

GEOLOGY OF MOUNT JURA, CALIFORNIA

BY C. H. CRICKMAY [2]

(*Abstract*)

Previous geological work by Diller and Hyatt shows Mount Jura to contain unfinished and requires revision and completion. The author is now engaged in an attempt to do this. This paper reports his progress.
a comprehensive Jurassic succession. But the work of these investigators is

Structurally the mountain is a series of schuppen thrust over one another from the east, and then overturned *en masse* toward the east by a greater overthrust from the west.

[1] Introduced by G. D. Louderback.
[2] Introduced by W. J. Miller.

The Jurassic succession consists of fifteen or more distinct formations. As far as these have been separated they may be roughly grouped as follows; descending order:

Upper Jurassic
- Foreman argillite, etcetera.
- Tuffs
- Bicknell "sandstone"
- Hinchman agglomerate

Middle Jurassic
- Red shale and agglomerate
- Conglomerate
- Black shale
- Mormon sandstone
- Tuffs
- Brown shale
- Thompson limestone
- Red shale
- Faut lavas and agglomerates

Lower Jurassic
- Hardgrave tuff
- Black limey argillite

DISTRIBUTION OF CRYSTALS AMONG THE THIRTY-TWO SYMMETRY CLASSES

BY AUSTIN F. ROGERS

(*Abstract*)

Of the 7,200 odd crystalline substances (both minerals and prepared compounds of the laboratory) described in Groth's "Chemische Krystallographie" (5 volumes, 1906-1919), 5,588 have been assigned to a particular crystal class, most of them with a reasonable degree of certainty.

A statistical study of the 5,588 crystalline substances reveals a number of interesting facts. In order of number of representatives the crystal classes are arranged as follows: Monoclinic prismatic, rhombic bipyramidal, triclinic pinakodial, rhombic bisphenoidal, monoclinic sphenoidal, hexagonal scalenohedral, rhombic pyramidal, ditetragonal bipyromidal, asymmetric, monoclinic domatic, and so on. Each of these has more than 20 known representatives; the other classes have fewer than 20 each. The monoclinic prismatic class has 2,786 representatives or about 50 per cent of the total. The first five classes named have together about 92 per cent of the total number. It is surprising to learn that the asymmetric class (triclinic pediad) is ninth in the list. In other words there are 22 crystal classes, each with fewer representatives than the asymmetric class.

This paper was not discussed because of lack of time.

ANNUAL DINNER

The annual dinner was held under the auspices of the LeConte Club, on Friday evening, at Stephen's Union. About 76 fellows and guests were present at the dinner, which was followed by an address by Mr. Henry W. Turner, "Observations on the Geology of the Sierra Nevada," which was of great interest to all those present.

On Thursday evening a smoker was held in Bacon Hall.

REGISTER OF THE 1930 MEETING

FELLOWS

F. M. ANDERSON
ELIOT BLACKWELDER
J. P. BUWALDA
BRUCE L. CLARK
ARTHUR S. EAKLE
EDWIN T. HODGE
CARLTON D. HULIN
OLAF P. JENKINS
J C. JONES
ANDREW C. LAWSON
GEORGE D. LOUDERBACK
W. D. MATTHEW
R. D. REED
AUSTIN F. ROGERS
HUBERT G. SCHENCK
SOLON SHEDD
N. L. TALIAFERRO
H. W. TURNER
T. WAYLAND VAUGHAN
W. P. WOODRING
CHARLES E. WEAVER

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF A JOINT SESSION OF SECTION E OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE AND MEMBERS OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT CLEVELAND, OHIO, JANUARY 1 and 2, 1931.

KIRTLEY F. MATHER, *Secretary*

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Session of Thursday, January 1, 1931

Report of the Secretary

Section E held three sessions on Thursday and Friday. None of the organizations related to this section was in session in Cleveland, but about 75 geologists attended the meeting and 27 papers were listed on the program. Edson S. Bastin, of the University of Chicago, Vice-President and Chairman of the Section, presided at the Thursday sessions, and Charles N. Gould, State Geologist of Oklahoma, was in the chair during the Friday morning session. The address of the retiring Vice-President George F. Kay of the University of Iowa, was presented Thursday afternoon. The annual dinner was greatly enjoyed by 40 geologists in the Hotel Cleveland Thursday evening. Dr. Bastin was toastmaster and called on Dean Kay, Professor J. E. Hyde of Western Reserve, Professor F. R. Van Horn of Case, Professor W. H. Hobbs of Michigan, Professor Kirtley F. Mather of Harvard, and Dr. Arthur Bevan, State Geologist of Virginia, for remarks. Dean Kay's address is printed in full in Part 1 of this Bulletin. The thanks of all in attendance are due to Professors Hyde and Van Horn for the excellent arrangements for the meetings.

TITLES AND ABSTRACTS OF PAPERS

BEDROCK FOOTINGS FOR DAMS IN THE UPPER MISSISSIPPI VALLEY

BY ARTHUR C. TROWBRIDGE

(*Abstract*)

Although the stratigraphic, structural and physiographic history of the upper Mississippi Valley region has been such that bedrock foundations for dams would be expected to occur in only a few places on Mississippi River and its main tributaries, careful geologic surveys have discovered at least partial footings on firm bedrock at shallow depths for a considerable number of the proposed dams, locks, dikes and abutments of the "9-foot channel project."

CURRENT INVESTIGATIONS OF OIL-FIELD WATERS

BY FRED B. PLUMMER

Read by title in the absence of the author.

BEREA SANDSTONE AND EUCLID BLUESTONE QUARRIES IN THE VICINITY OF CLEVELAND

BY FRANK R. VAN HORN

(*Abstract*)

This region has been the location of a building stone industry for over 75 years. The Euclid bluestone horizon belongs to the Bedford shale formation of the lower Mississippian. The Berea sandstone lies immediately above the Bedford and contains what are probably the largest sandstone quarries in the world. Lantern slides of both horizons were shown.

TEXTURAL FEATURES OF THE SAINT PETER SANDSTONE OF ARKANSAS[1]

BY ALBERT W. GILES

(*Abstract*)

A comparison of the average results of a large number of mechanical analyses of Saint Peter sandstone from Illinois, Missouri and Arkansas clearly indicates the increasing fineness of the sand in proceeding southward in the Mississippi Valley. This increase in fineness is attributable to greater attrition resulting from farther transportation from the original source of the sand in the older formations of northern United States and Canada.

An investigation of 5 samples of the Saint Peter sand selected as typical of the formation in widely separated localities in northern Arkansas was undertaken with particular reference to the various shapes the grains exhibit. The number of grains rounded was found to decrease with increasing fineness of the grains. The angularity of the grains is ascribed to secondary enlargement.

[1] Published with the permission of Mr. George C. Branner, State Geologist of Arkansas.

Pitting is a characteristic feature of Saint Peter sand grains. Most of the larger grains are pitted and may have from 5 to 25 pits on their surfaces, but in small grains pitting is more rarely developed.

Rounded grains are almost without exception frosted, but angular grains are either not at all frosted, or only partly frosted. Small grains are as a rule unfrosted.

During the progress of the study of the frosting of the Saint Peter sand grains it became apparent that the origin of the rough surfaces of the grains was due not only to wind abrasion but also to solvent action of underground water subsequent to the deposition of the sand. The resulting "etching" is difficultly distinguishable from frosting in the coarser grains but is a conspicuous feature of the surfaces of the finer grains, and of many fragments and crystals of secondary quartz broken off the larger grains.

EROSION SURFACES IN EASTERN OHIO

BY KARL VER STEEG

(*Abstract*)

Projected profiles and field study of an area of approximately 4,000 square miles in the rugged, unglaciated portion of eastern Ohio, indicate the presence of two well-defined erosion surfaces, the Harrisburg on the uplands and stream divides, at an average elevation of 1,200 to 1,300 feet a.t. and the Worthington (Lexington) at an altitude varying from 900 to 1,100 feet a.t. The Harrisburg in Ohio is correlated with the Allegheny Plateau upland in Pennsylvania. The Worthington in eastern Ohio is correlated with Kentucky Lowland (900 to 1,000 feet a.t.), located west of the conglomerate escarpment. This area, of which the Lexington Plain is a part, slopes westward and is coextensive with the lowlands in western Ohio, much of which lies at about 900 feet a.t.

The writer recognizes the existence of three distinct erosion surfaces in the northern Appalachians and Allegheny Plateau region; the Schooley (Kittatinny) on the ridge crests of the folded Appalachians, the Harrisburg on the weaker rock formations in the valleys of eastern Pennsylvania and coextensive with the upland erosion surface beveling the Allegeheny Plateau region and a third, the Worthington (Lexington) erosion level, well developed in Ohio and Kentucky, and which by virtue of its position below the Harrisburg is correlated with the Somerville of eastern Pennsylvania and New Jersey. This seems to the writer to be the most logical interpretation in the light of present knowledge concerning Appalachian erosion surfaces.

CAVERNS AND ASSOCIATED FEATURES IN THE VALLEY OF VIRGINIA

BY ARTHUR BEVAN

(*Abstract*)

Numerous large caverns are known in the Valley of Virginia, especially in the northeastern third, or Shenandoah Valley.

The Valley of Virginia consists essentially of an extensive lowland—the valley-floor peneplain of Stose—between the Blue Ridge on the southeast and the valley ridges on the west. The floor truncates highly folded and overthrust Cambrian, Ozarkian, Canadian, and Ordovician limestones, dolomites,

and shales. Its elevation ranges from about 500 feet toward the Potomac to about 2,500 feet in the south-central part. The largest streams, such as Shenandoah River, have cut a few hundred feet below the valley floor and their numerous tributaries have dissected the area to a submature topography.

The several large caverns in the Valley afford numerous problems that await critical field study and interpretation. As most of these caverns have recently been made accessible to the public these problems can be readily attacked. Some of the problems are: (1) The relative importance of percolating or "standing" ground water and underground streams in the origin of the caverns, (2) the relation of caverns in inclined beds to surface drainage and to the water table, (3) causes of deposition of many peculiar forms, such as inclined "shields," branching stalactites and stalagmites, "telescoped" stalactites, and (4) interrelation of solution and deposition. In brief, the whole cycle of development of large caverns in inclined beds needs a thorough study and the Valley of Virginia offers an excellent field for it.

LOESS DEPOSITS AND THEIR NOMENCLATURE

BY MORRIS M. LEIGHTON

(*Abstract*)

The loess deposits of the Pleistocene were the product of periodic accumulation of wind-blown dust rather than continuous accumulation. They have distinct stratigraphic positions in the Pleistocene system and represent climatic conditions favorable for wind erosion and transportation. The loesses of the early interglacial epochs are not so well known as those of the later. Field studies of the past 10 years have shown that a wide-spread deposition of loess was laid down in the latter part of Sangamon interglacial epoch, after the development of a mature profile of weathering on the Illinoian drift. This loess deposit, however, was weathered before the overlying Peorian loess was laid down. Recently discovered field evidence shows that the Peorian loess, a correlative of the Iowan drift-sheet, was an immediate forerunner of the Shelbyville substage of the Wisconsin series and that the advance of the Iowan ice-sheet initiated the Wisconsin series. The loess deposits on the Wisconsin drift were essentially a continuation of the loess deposits of Peorian times, there being no record of an interval of weathering between their accumulation. The stratigraphy, time relations, faunas and physical character of the deposits demand a satisfactory nomenclature.

Read by title in the absence of the author.

GLACIATION NORTHEAST OF YELLOWSTONE NATIONAL PARK

BY ARTHUR BEVAN

(*Abstract*)

The high plateaus and mountains north, northeast and east of Yellowstone National Park have been extensively glaciated. The glaciers consisted of a few ice-caps and numerous large valley glaciers. Several small glaciers are found now among the highest peaks of the Beartooth Range northeast of the park.

The southwestern slope of the Beartooth Range was covered by a large ice-

cap, from which tongues of ice spilled across the main divide of the range and moved toward the northeast down several valleys to the Great Plains. All of the main valleys on the northeast slope of the range were occupied by large glaciers.

Glacial erosion was pronounced. Scores of cirques and lake basins were formed, as well as the usual valley features. "Crater cirques" were developed in the heart of the range.

Two systems of moraines were deposited. Some terminal and lateral moraines are about 1,000 feet high. There is some evidence of deposits of a still earlier stage, thus indicating at least three stages of glaciation in the Beartooth Range.

GEOLOGICAL EVIDENCES OF EARLY MAN IN AMERICA

BY HAROLD J. COOK

(*Abstract*)

There is particular need at this time for active geologists to take a greater personal interest in helping to uncover and determining accurately all possible geological evidence bearing on the problems of really ancient man in America. The long array of striking evidences found the past few years in Florida, Texas, Oklahoma, New Mexico, and elsewhere, tend to emphasize the validity of the antiquity of mankind on this continent; perhaps even back into Tertiary times. There is a real need for able, careful studies of many localities and situations where such discoveries have been made, or are apt to occur; and it is important that all geologists who chance to work in Pleistocene or late Tertiary deposits in this country keep constantly on the watch for such evidences.

We now have so much good evidence that man was in America far earlier than has generally been believed, and was also probably rather widely scattered, that it behooves all geologists working in places where local deposits of comparatively late origin may occur, to be constantly on the alert. Someone is going to find finer things of this sort than have yet been found. Also I wish further to urge the great need of more geologists taking a hand when such things are found, to help determine without bias, the real age of the deposits in which they occur, using all the methods at hand to this end.

In the absence of the author this paper was presented in abstract by Kirtley F. Mather.

AQUATIC DINOSAUR FROM THE NIOBRARA OF WESTERN KANSAS

BY M. G. MEHL

(*Abstract*)

Dinosaur remains in marine sediments are very rare. Two specimens, both very fragmentary, have been reported from the Niobrara of western Kansas. A splendid specimen from the chalk beds of western Kansas has been added to the collections of the University of Missouri through the efforts of Mr. Virgil Cole, a former student.

Although not sufficiently complete for a mounted display the remains represent most of the essential structures, some in complete detail. The bones

indicate an animal with a total length of about 15 feet of which about one-third is contributed by a moderately slender tail. The body was broad and flat with length and breadth almost equal. The femora were directed almost horizontally and slightly back. The tibia are exceptionally thinned distally and widely expanded laterally. The dermal scutes, represented by more than 50 complete units and twice as many fragments, indicate a comparatively light spinous armor. These features—flat body, horizontal femora, paddlelike tibia, and reduced armor—leads to the belief that this type of dinosaur was a turtlelike development as much at home in the open sea as were the large marine turtles of the time.

This new Niobrara specimen belongs to the Stegosauroidea and most likely to the Ankylosauridea. The type material of Hierosaurus from the Kansas chalk has little in the way of distinguishing characteristics, but its isolated armor plates can not be distinguished from some of the plates of the present specimen.

FORAMINIFERA AND OSTRACODA FROM THE SUNDANCE (JURASSIC) OF WYOMING

BY PHILIP MOREY

(*Abstract*)

A microfauna from the Sundance formation in the Lander region, Wyoming, contains several genera of foraminifera and ostracoda. *Robulus, Globigerina, Frondicularia, Nodosaria, Clavulina, Cytherella, Cythere,* and one undetermined genus of foraminifera are present. This is the first time foraminifera have been listed from Jurassic strata in North America. The foraminifera and ostracoda approach abundance only in the lowest part of the formation but are present throughout the lower 200 feet.

In the absence of the author this paper was presented in abstract by M. G. Mehl.

CORRELATION OF CONTINENTAL DRIFT THEORIES AND EARTH'S MAGNETIC POLES AND FOCI

BY D. W. LONGFELLOW

(*Abstract*)

Mr. Frank B. Taylor advanced a theory of continental drifting a number of years ago. Among other movements, he described a crustal drifting of North America away from Greenland during the Tertiary period.

Several years ago the writer developed a theory of continental movement based on the peculiar positions of the earth's magnetic poles and foci. Remarkable results were obtained when it was assumed that originally both magnetic poles and the four foci all lay on a single great circle around the earth and the underlying continents were moved with the north magnetic pole and North American focus to this assumed original position.

Taylor's crustal drifting seemed to have no place in this movement because

[1] Introduced by E. B. Branson.

the remarkable results were obtained by keeping Greenland and North America in their same positions relative to each other.

Just recently the writer discovered that by placing North America adjacent to Greenland, as described by Taylor, after placing Greenland in its original position, according to his own theory, Belle Isle strait was brought right up to Dingle Bay in the southwest of Ireland.

Suess, a number of years ago, remarked about the great similarity of these two points, in his "The Face of the Earth."

If, after making the above original construction, Newfoundland and its banks are placed in their original position relative to North America, as described by Wegener's theory of continental drift, then the banks fit neatly into the Bay of Biscay, which they greatly resemble in shape.

It is concluded that this is confirmatory evidence that all three movements probably did take place but that Taylor's, at least, was not deep-seated enough to move the magnetic material of which the magnetic poles of the earth are composed.

CURRENT THEORIES OF EARTH ORIGIN

BY KIRTLEY F. MATHER

(*Abstract*)

The planetesimal hypothesis of Chamberlin and Moulton should be critically scrutinized in the light of the facts and principles on which Jeans and Jeffreys base their tidal hypothesis of earth origin. This survey indicates certain harmonies and discords between the two theories. The fundamental principle of dynamic encounter is common to both, but the mode of organization of the planets from the resulting nebula and the juvenile history of the earth are in striking contrast in these two views of the genesis of the solar system. It is, however, possible to retain much of the essential fabric of the planetesimal hypothesis and make minor modifications, based on certain ideas of Jeans and Jeffreys, which enable it to meet the demands resulting from recently acquired knowledge of the internal structure of the earth. Most important of these modifications is that which would suppose the "earth nucleus" in the new-formed nebula to have contained nine-tenths rather than only a third or a fourth the present mass of the earth. Although the Jeans-Jeffreys tidal theory does not include the concept of earth-enlargement by planetesimal accretion, it is obvious that such growth has taken place in the past and is even now continuing on a small scale. As pointed out by Chamberlin, the "resisting medium" of Jeans and Jeffreys must take on planetesimal organization. Many of the discords between the two major theories of earth origin may therefore be reduced nearly or quite to disappearance.

FOURTH GREENLAND EXPEDITION OF THE UNIVERSITY OF MICHIGAN

BY WILLIAM H. HOBBS

(*Abstract*)

Aided by a grant of money from the Carnegie Institution of Washington, and by an American-Scandinavian Fellowship for Mr. William S. Carlson, the Fourth University of Michigan Greenland Expedition set out in the summer of 1930. It was composed of two parties: One, under W. S. Carlson, based in latitude 72 degrees north on the west coast east of Upernivik; and

the other, under Mr. E. C. Schmeling, at Ivigtut in extreme south Greenland, latitude 61 degrees north. The former stations of the expedition at Camp Michigan and at Mount Evans, both near the arctic circle, have been closed since 1926 and 1929 respectively. The work of the Fourth Expedition is in character both aerological and glaciological. Daily pilot balloon ascents began at both stations on September 1 and will be continued for the period of one year. Studies of the glacier front will be carried out to determine changes of position in the past and to permit reliable values to be obtained in the future.

DETERMINING THE THICKNESS OF GLACIAL DRIFT BY SEISMIC MEANS

BY L. DON LEET

(*Abstract*)

Geologists in glaciated areas are frequently in need of information concerning the thickness of glacial drift overlying solid rock formations, where there are no wells to supply it. Students of preglacial drainage systems are particularly handicapped by a lack of well data in critical areas.

The seismic method of prospecting geologic structure, developed in recent years, could become an effective tool for geologists attacking such problems.

The fundamental principles of seismic prospecting are outlined with special reference to their application in determining the thickness of glacial drift. The accuracy and rapidity with which such work could be done are discussed.

In the absence of the author this paper was presented in abstract by Kirtley F. Mather.

DINWOODY FORMATION OF WESTERN WYOMING

BY H. GLENN WALTER[1]

(*Abstract*)

The Dinwoody formation of western Wyoming consists of buff and gray calcareous shales, sandy shales, and sandstones 40 feet to 200 feet thick. It is best exposed along the eastern foothills of the Wind River Mountains. Few fossils from this formation have been listed, all of them invertebrates and mainly pelecypods. Because of the lack of fossils, the decided lithologic change from the Phosphoria of Permian age, and the gradation into Lower Chugwater, of questionable Lower Triassic age, there has been considerable controversy over the age of the formation.

At several localities in the eastern foothills of the Wind River Mountains the writer has collected many invertebrates of considerable variety and fair preservation. This fauna is chiefly pelecypod, the genera *Mytalina*, *Aviculopecten*, *Blakewellia*, *Edmondia*, and others being represented. Two species of brachiopods and two species of gastropods have been recognized.

It is the writer's opinion that the fauna is more closely related to the Permian than to the Triassic. A comparison of this fauna with collections made near Boxelder, Colorado, and Jelm, Wyoming, indicates a possibility that further evidence may be obtained on the Permian-Triassic contact.

[1] Introduced by E. B. Branson.

In the absence of the author this paper was presented in abstract by M. G. Mehl.

BRAZER FORMATION OF NORTHERN UTAH AND ITS TELOTREMATA

BY F. GUNNELL[1]

(*Abstract*)

The Brazer formation in northern Utah consists of 2,000 feet of limestone, dolomite, shale, sandstone and quartzite. A distinct unconformity exists between the Brazer and underlying Madison limestone of the Lower Mississippian. No unconformity is distinguishable between the Brazer and the overlying Wells formation of the Pennsylvanian. Eighteen old and 8 new species included in 12 genera of Telotremata are recognized. The fossiliferous upper portion of the formation from which the fossils were collected contains forms similar to those which occur in the Amsden of Wyoming, the Maroon of Colorado, and the Chester and Saint Genevieve of the Mississippi Valley.

In the absence of the author this paper was presented in abstract by M. G. Mehl.

SEDIMENTATION AS A RECORD OF ENVIRONMENT

BY CARROLL LANE FENTON AND MILDRED ADAMS FENTON

(*Abstract*)

Sedimentation, being both a result of and a factor in the inorganic environment, necessarily forms a record of that environment. The accuracy and detail of the record depend, in marine situations, on the nature of the sedimentary material and the depth and movements of the water under which it is deposited. Optimum conditions appear to be afforded by fine clastics and shallow-water, even intertidal conditions. Instances, ranging from the Belt to the Devonian, are reviewed, in which sediments preserve in some detail a record of the environment of the organisms fossilized in them.

FISH REMAINS OF THE WESTERN INTERIOR TRIASSIC

BY E. B. BRANSON AND M. G. MEHL

(*Abstract*)

Excepting the description of two species of Ceratodus from the Triassic of Texas, little mention has been made of fish remains in the Triassic of the western interior States. A considerable number of Ceratodus teeth from Arizona and New Mexico leads the writers to conclude that only one species is represented in the Triassic of the Southwest and that assumed specific differences are the result of differing degrees of abrasion, different ages of the individuals, and differences depending on whether the teeth were from the upper or lower dentition.

No specimens of Ceratodus are known from the Triassic north of New Mexico, but fishes of other kinds have been found near the top of the Chugwater in two widely separated localities in Wyoming.

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[1] Introduced by E. B. Branson.

The Wyoming Triassic forms are all very small and would ordinarily escape detection in a casual examination of the outcrop. They consist of isolated scales and teeth and represent at least three new genera and possibly four or five new species.

This paper was presented extemporaneously by M. G. Mehl.

NEW BIRD RECORD FROM THE DAKOTA SANDSTONE OF COLORADO

BY M. G. MEHL

(*Abstract*)

The only bird record of any degree of certainty that bridges the gap between the Jurassic "reptile bird" and the remains in the Niobrara of western Kansas has been a single footprint in the Dakota sandstone of Kansas. Other reported finds from the same formation and State have been disputed and lost and the supposed bird remains from the Morrison of Wyoming have been questioned.

Through the courtesy of Professor Junius Henderson, of the University of Colorado, the writer has been permitted to study a series of about 70 bird tracks from the base of the upper massive sandstone of the "Dakota" near Golden, Colorado. The tracks, in normal progression mark a trail such as is made by a wading bird the size and build of the common curlew.

The toes are long and slender and claw tipped. The length of the foot is about 2 inches, including a relatively long posterior toe that rises from above the level of the plantar surface. The stride is about 3 inches.

MISSISSISSIPPIAN AND PENNSYLVANIAN CONODONTS FROM MISSOURI

BY F. GUNNELL

(*Abstract*)

Reconnaissance collecting of conodonts from Missouri Mississippian has shown that they are fairly abundant in the Grassy Creek shale, Louisiana limestone and Hannibal shale. In the Pennsylvanian they have been found in abundance in the Cherokee, Kansas City, Lansing, and Wabaunsee formations, and in channel sandstones of uncertain age. A 3-pound sample from one member of the Lansing contained *Gnathodus*, *Clenognathus*, *Polygnathus*, *Lonchodus*, *Distacodus*, *Acodus*, *Prioniodus*, *Subprioniodus*, *Hindeodella*, *Bryanthodus*, and 2 new genera. Although the great variety of forms from this sample is probably not a true indication of conodont distribution in the Pennsylvanian formations, it does not greatly exaggerate their abundance. Previously, conodonts have not been described from the Pennsylvanian of North America, and the majority of Mississippian forms were found in the Hardin sandstone of Tennessee, and the Barnett shale of Texas. Some Pennsylvanian specimens resemble the teeth of a European Saurichthys, while others are similar to scales of Lepitotes. These relationships are indicative of the zoological position of conodonts. Many formations that are devoid of megascopic fossils contain conodonts. This factor together with their abundance, microscopic size, stratigraphic range, and distinct character favors their use in the correlation of formations from well cuttings.

In the absence of the author this paper was presented in abstract by M. G. Mehl.

The address of the retiring Vice-President of Section E was presented under the following title.

CLASSIFICATION AND DURATION OF THE PLEISTOCENE PERIOD

BY GEORGE F. KAY

SESSION OF FRIDAY, JANUARY 2, 1931

TITLES AND ABSTRACTS OF PAPERS

PETROGRAPHIC STUDY OF SANDSTONE MEMBERS IN THE JEFFERSON CITY AND COTTER FORMATIONS AT ROLLA, MISSOURI

BY OLIVER R. GRAWE AND JAMES S. CULLISON

(*Abstract*)

The Jefferson City formation as previously mapped in the Rolla Quadrangle, Missouri, has been remapped and divided into two formations, the Jefferson City, proper, and the overlying Cotter. Although the primary basis for this division is paleontological, the practical basis is the occurrence of a persistent sandstone at the base of the Cotter, which can be traced throughout the area. Texture analyses are particularly useful in recognizing this sandstone and discriminating between it and the upper Jefferson City sandstones with which it is associated. Shape of grain and quantitative heavy mineral analyses are not very helpful since the sand and heavy mineral grains of both formations are very similar. The total heavy mineral content of these sandstones is only 0.05 to 0.005 of one per cent.

The study suggests that the Jefferson City and basal Cotter sandstones are of marine origin and were derived largely from preexisting sandstones, but rocks undergoing their erosion cycle may have contributed to a minor extent, for the heavy mineral grains which were deposited with the quartz grains are of two types: Round, resistant grains of leucoxene, tourmaline and zircon; and angular, nonresistant grains of biotite, chlorite, epidote, hornblende and tremolite. Since the basal Cotter sandstone is finer and better sorted than the Jefferson City sandstones, slight differences in sedimentation prevailed during the deposition of the two sandstones. This may correlate with the known wider expanse of the Cotter sea. Since the deposition of these sandstones, other minerals were introduced. These are of two types: ore minerals such as chalocopyrite, galena, pyrite and sphalerite; and alteration products such as limonite and siderite.

PHYSICAL ANALYSES OF THE CHUGWATER FORMATION

BY RAYMOND M. TROWBRIDGE[1]

(*Abstract*)

Physical analyses of 56 members of the Chugwater formation were made in order to determine the physical characters of the deposit. Samples were

[1] Introduced by E. B. Branson.

taken from every member of the 1,680 feet of the formation on Bull Lake Creek Canyon, 35 miles northwest of Lander, Wyoming. The size of the grains ranges from those too small to be measured up to 0.2 millimeters, with most of them below 0.05 millimeters. Pure, colorless, angular quartz grains irregularly coated with iron oxide predominate, but mica grains are present throughout the formation, and in many places give rise to laminations. Near the top of the formation, one sandstone bed 15 feet thick contains well rounded, frosted and pitted sand grains, but it is unique. Further investigations are in progress.

In the absence of the author this paper was presented in abstract by M. G. Mehl.

CAUSAL RELATIONSHIPS OF HIGH EASTWARD EQUATORIAL WINDS AND RELATED PHENOMENA

BY BERT RUSSELL

(*Abstract*)

The earth's rotation may be maintained by a preponderance of outrunning eastward winds; and in particular by an inferred "wind river" just below the stratosphere and analogous to annular rivers known to exist in other planets. Such rivers, tending to maintain or to increase any initial relative rotation in mutually irradiating bodies like those of our solar system, apparently could arise from an asymmetry in light-pressure relationships—a "hot spot" in each planet's atmosphere being located in the "afternoon" quadrant and therefore "off-center" with reference to the line between gravitational centers. The mysterious double-diurnal variation in atmospheric pressure (as perhaps also that in potential gradient) may be connected with (*a*) "froth-blowing" effects of solar radiation upon the inferred wind river in its "forenoon" quadrant and (*b*) "comet's-tail" effects thereon in its "evening" quadrant. Roughly meridional and horizontal "wind-rolls" may be frictionally produced between the inferred wind river and the respective slower strata below and above; "outcroppings" at the ends of such rolls appearing as the "lows" and the "highs" of weather maps. (Compare Bjerkness theory of sun spots.)

FAULTS ON THE EASTERN FLANK OF THE WIND RIVER MOUNTAINS, WYOMING

BY CHARLES D. GLEASON [1]

(*Abstract*)

The Wind River Mountains are anticlinal in structure. The eastern flank, unlike the western, has been supposed to be relatively free from faults, but the writer's investigations in the Lander, Wyoming, area indicate that faults are numerous. In addition to faults already described there are others of equal importance. Most of these are strike faults and have been overlooked except in very detailed mapping. Smaller strike faults are intimately associated with sharp anticlines on the flank of the major structure.

[1] Introduced by E. B. Branson.

In the absence of the author this paper was presented in abstract by M. G. Mehl.

RETREAT OF THE FRONT OF THE LAST ICE-SHEET IN NEW YORK AND NEW ENGLAND

BY FRANK B. TAYLOR

(*Abstract*)

A characteristic feature of the drift of the Wisconsin ice-sheet in the Great Lakes region is the remarkable series of recessional marginal moraines, which mark periodic oscillations of retreat. The oscillations affected the whole ice-sheet, so far as known, and the inference seems sure that they must be recorded in the drift of all the regions covered.

Certain geologists in New York and New England, failing to recognize moraines and border drainage features comparable to those of the Great Lakes area, have concluded that during its waning phase the ice-sheet remained stagnant and hence made no record of oscillations during retreat.

In this paper the writer gives a brief account of results of careful studies made during parts of eighteen summers in these areas. Moraines and border drainage features were found in abundance, but they are very different from those in the west. Nearly all are short fragments, largely terminal deposits of narrow ice-tongues, with many kames and sometimes with banked morainic deposits on the hillsides, and also with associated marks of border drainage. It is difficult in some parts to make out continuous positions of alignment of the ice front, but the features show oscillating retreat as clearly as they do in the west.

Read by title in the absence of the author.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 42, PP. 335-384 MARCH 31, 1931
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE TWENTY-SECOND ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT TORONTO, CANADA, DECEMBER 29-31, 1930.

B. F. HOWELL, *Secretary*

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Session of Monday, December 29

The Society was called to order by President Twenhofel for its twenty-second annual meeting at 2:05 p.m. The report of the Council was the first business in order.

Report of the Council

To the Paleontological Society, in twenty-second annual meeting assembled:

The business of the Society which was carried on during the past year is covered by the reports of the Secretary and the Treasurer and those of the Service Committee and the Committee on Journal. The Secretary's and the Treasurer's reports are presented herewith.

Secretary's Report

To the Council of the Paleontological Society:

I have the honor to present the following report for the year ending December 28, 1930:

Meetings.—The Proceedings of the twenty-first annual meeting of the Society, held at Washington, December 26-28, 1929, have been published in volume 41, number 1, pages 181-227, of the Bulletin of the Geological Society of America.

The Council's proposed nomination for officers for 1930 was mailed to the Fellows and members in March, 1930, with the announcement that the twenty-second annual meeting would be held at Toronto, Ontario, at the invitation of the University of Toronto.

Membership.—The Society has lost one correspondent, Professor J. F. Pompeckj, and three Fellows, Dr. A. R. Crook, Professor W. D. Matthew and Professor J. L. Tilton, by death during the year. Twenty-two new members were elected last December, twenty-six have just been elected, and eight more await election at this meting. One new correspondent, Dr. Jan Koliha, was elected at the last annual meeting, and the Council will propose two others, Mr. Frederick Chapman and Dr. H. Yabe, for election at the present meeting. Eight of our members, Messrs. C. G. Croneis, M. H. Hanna, S. H. Knight, E. R. Pohl, G. G. Simpson, P. S. Warren, J. M. Weller, and H. E. Wood, have just been elected to fellowship in the Geological Society of America, and will now, in accordance with our custom, be elected Fellows of the Paleontological Society. Our total membership at the beginning of the year was 373. If the members and correspondents still to be voted on are elected our membership will be at the end of this year 409.

Publications.—The Proceedings for 1929 and four articles, totaling 77 pages, have been published in the Bulletin of the Geological Society of America during the year. The Proceedings and copies of three of the articles have been distributed to the correspondents and members. The copies of the other article, only recently received from the printer, will be distributed in the near future.

Pacific Coast Section—This section of the Society met at the University of California, Berkley, Saturday, Februarry 22, 1930, when a program of 14 papers was given. The proceedings of this meeting are given on later pages.

The Secretary cannot close this report without a tribute to his predecessor, whose long and efficient services to the Society are well known to every Fellow and member. Dr. Bassler prepared the manuscript of the Proceedings of the 1929 meeting, and has aided the Secretary in his duties all through the year. The Secretary gratefully acknowledges this assistance, and will try to maintain the high standard of service to the Society which has been set for his emulation.

Respectfully submitted,

B. F. Howell,
Secretary.

Princeton, N. J., *December 28, 1930.*

Treasurer's Report

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending with December, 1930:

Credits

Cash on hand December 27, 1929:			
Connecticut Savings Bank		$1,592.96	
Second National Bank		119.91	
Membership dues collected in 1930		597.00	
Interest, Connecticut Savings Bank		81.12	
			$2,390.99

Debits

Secretary's office:			
Secretary's allowance for 1929	$100.00		
Clerical aid for 1929	25.00		
Postage and stationery (1929)	58.85		
Postage and stationery (1930)	130.90		
		$314.75	
Treasurer's office:			
Treasurer's allowance for 1929	$25.00		
Postage and stationery (1929)	21.00		
		46.00	
Pacific Coast Branch:			
Printing programs for the summer meeting of 1930	$22.00		
		22.00	
Publication:			
Reprints from volume 40, Bulletin of the Geological Society of America	$112.04		
Reprints of volume 41	57.43		
		169.47	
Miscellaneous:			
Checks returned for lack of funds	$9.00		
		9.00	
			$561.22
Balance on hand December 27, 1930			$1,829.77
Outstanding dues:			
Members 1 year in arrears—12 at $3		$36.00	
Members 2 years in arrears—11 at $6		66.00	
Members 3 years in arrears—7 at $9		63.00	
			$165.00
Bills outstanding:			
Secretary's allowance and clerical aid for 1930			$125.00

During 1930 the Society's income was the greatest in its history, the income from membership dues being almost $600. At the same time the expenses have been abnormal so that the net gain has been only $116.90. Two factors have caused the abnormally large expenditure, first being the fact that the reprints from Bulletin 40 of the Geological Society of America were not supplied in time for distribution last year (due to an error at the printers) and that the cost of these and of their distribution ($112.04 + $21.50) has fallen in this year instead of last; the second being that the expenses of the Secretary's office for the current year have been paid as they were incurred, whereas in former years they have been carried personally by the Secretary until after the close of the year. In other words, the small gain for the year is apparent rather than real.

Very truly yours,

CARL O. DUNBAR,
Treasurer.

New Haven, Connecticut, *December 27, 1930.*

APPOINTMENT OF AUDITING COMMITTEE

Professor Twenhofel referred the accounts of the Treasurer to an Auditing Committee, consisting of Dr. A. F. Foerste and Professor Arthur C. McFarlan.

ELECTION OF MEMBERS

The Secretary announced the election of the following new members for 1931:

CARL COLTON BRANSON, Department of Geology, Brown University, Providence, Rhode Island.

ANNE EDITH BURGESS, 221 Grant Avenue, Highland Park, New Brunswick, New Jersey.

ARTHUR BAILEY CLEAVES, 25 Perkins Hall, Oxford Street, Cambridge, Massachusetts.

EDWIN HARRIS COLBERT, 500 Riverside Drive, New York City.

E. R. ELLER, 114 Tillinghast Place, Buffalo, New York.

BROOKS FLEMING ELLIS, 85 Waller Avenue, White Plains, New York.

FREEMAN FOOTE, '79 Hall, Princeton, New Jersey.

MADELEINE ALBERTA FRITZ, 2 Spadina Road, Toronto, Ontario.

JOHN DANIEL GILBOE, 2216 Park Way, Bakersfield, California.

BENJAMIN GILDERSLEEVE, Damascus, Virginia.

CAROLINE ELLA HEMINWAY, 150 Elm Street, Northampton, Massachusetts.

CURTIS J. HESSE, Bacon Hall, University of California, Berkeley, California.

RACHEL A. HUSBAND, American Museum of Natural History, New York City.

FORBES MEREDITH HUTCHINS, 3524 Ontario Avenue, Montreal, Quebec.

CHARLES ALBERT KINSEY, Belgrade, Montana.

MOSES MARION KORNFELD, Atlanta Oil Producing Company, 906 Central Building, Wichita, Kansas.

DONALD JOHNATHAN MACNEIL, Department of Geology, Princeton University, Princeton, New Jersey.

EDWIN DINWIDDIE MCKEE, Grand Canyon, Arizona.

EDWIN JANNEY MOLES, Jr., 52 Holder Hall, Princeton, New Jersey.

HORACE GARDINER RICHARDS, 509 Woodland Terrace, Philadelphia, Pennsylvania.

WILLIAM E. SCHEVILL, Museum of Comparative Zoology, Cambridge, Massachusetts.

ROBERT R. SHROCK, 205 Sciene Hall, Madison, Wisconsin.

SIDNEY RICHMOND SWEET, Bridgeport, Nebraska.

V. L. VANDER HOOF, Bacon Hall, University of California, Berkeley, California.

HERBERTA LILLIAN VAN PELT, 6043 St. Lawrence Avenue, Chicago, Illinois.

G. LESLIE WHIPPLE, Bacon Hall, University of California, Berkeley, California.

NEW NOMINATIONS AND ELECTION TO MEMBERSHIP

The following six additional nominations to membership, which had been received by the Secretary too late for inclusion in the printed ballot, having been approved by the Council, were submitted to the Society for action:

PAUL B. BUNTON, 402 Transportation Building, Washington, D. C. Invertebrate paleontology. Proposed by R. S. Bassler and C. E. Resser.

ALICE JEANETTE JONES, Box 671, Mount Holyoke College, Northampton, Massachusetts. Invertebrate paleontology. Proposed by Mignon Talbot and B. F. Howell.

LOUIS RICHARD PATMONT, 520 Rose Court, Santa Rosa, California. Invertebrate paleontology. Proposed by Ralph W. Chaney and B. F. Howell.

JOHN C. F. SIEGFRIEDT, Red Lodge, Montana. Vertebrate paleontology. Proposed by Richard M. Field, B. F. Howell, C. E. Resser, and W. J. Sinclair.

DANA WELLS, 633 Spruce Street, Morgantown, West Virginia. Invertebrate paleontology. Proposed by R. S. Bassler and E. O. Ulrich.

ROBERT THOMAS DAUBIGNY WICKENDEN, Geological Survey of Canada, Ottawa, Ontario. Micropaleontology. Proposed by E. M. Kindle and F. H. McLearn.

It was moved and carried that the By-Laws be suspended and the Secretary instructed to cast the vote of the Society for the election of these six nominees to membership.

ELECTION OF CORRESPONDENTS

The Secretary then presented the names of two distinguished foreign paleontologists, Mr. Frederick Chapman, Lecturer in the University of Melbourne, and Paleontologist of the National Museum of Victoria, Mel-

bourne, Victoria, and Dr. Hisakatsu Yabe, Professor of Geology and Paleontology in the Tohoku Imperial University, Sendai, Japan, who were recommended by the Council for election as Correspondents. These gentlemen were unanimously elected.

ELECTION OF FELLOWS

The Secretary then laid before the Society a recommendation of the Council that the following members of the Society, who had just been elected Fellows of the Geological Society of America, be elected to fellowship in the Paleontological Society:

C. G. Croneis	G. G. Simpson
M. A. Hanna	P. S. Warren
S. H. Knight	J. M. Weller
E. R. Pohl	H. E. Wood

The recommendation was approved unanimously.

AMENDMENT OF THE CONSTITUTION

The President informed the Society that the Council believed that the Constitution should be amended so that ex-presidents would remain as members of the Council for three years after their terms of office. The Secretary explained that the Constitution required that notice of the submission of a motion for amendment must be submitted in print to all Fellows of the Society at least three months previous to the meeting at which the amendment was to be voted on. The Society then voted unanimously that the Secretary be instructed to inform the Fellows that such an amendment would be put to vote at the next annual meeting, and that this information be distributed with the preliminary ballot for officers for 1932 in the spring of 1931.

MEMORIAL OF J. F. POMPECKJ

A memorial of Professor J. F. Pompeckj, Correspondent of the Society, who died on July 8, 1930, was read by the Secretary.

MEMORIAL OF WILLIAM D. MATTHEW

A memorial of Professor William D. Matthew, Fellow of the Society, who died on September 24, 1930, which had been prepared by Professor W. K. Gregory, was read by the Secretary.

The chairman of the committee which had been appointed at the 1928 annual meeting to investigate the probable cost and possible ways of

financing increased facilities for the publication of paleontological papers then presented the following report for the committee:

REPORT OF COMMITTEE ON INCREASED PUBLICATION FACILITIES

In 1928 the Society appointed a committee to investigate the necessity of increased facility for the publication of paleontological papers and to gather information about the probable cost and possible ways of financing such publication. After carefully looking into the matter, the committee reported at the last annual meeting of the Society that there seemed to its members to be a need for increased facilities for the publication of two kinds of papers—short articles, which could be printed in a journal, and long ones, which could not be printed in a journal; and it recommended that the Society instruct the Service Committee to assist authors to find publishers for their longer papers and to gather information as to the needs for additional facilities for the publication of such papers, and that it authorize the Special Committee to investigate the possibility of the Society's joining the Division of Economic Paleontologists and Mineralogists of the American Association of Petroleum Geologists in supporting the *Journal of Paleontology*. The Society approved these recommendations and instructed the committee accordingly. The members of the Society present when the report was read expressed a willingness to have their dues increased to $5 if they might thereby receive a journal.

During the past year the present committee has been conferring with the officers of the Division of Economic Paleontologists and Mineralogists and with the officers of the Paleontological Society, endeavoring to assist them in formulating a definite proposal for cooperation in the support of, and use of, the *Journal of Paleontology* that could be presented to the Society at this meeting. As a result of these conferences the committee has been authorized by the officers of the two societies concerned to present to this Society, with a recommendation for its favorable consideration, the following plan for bringing about cooperation by the Paleontological Society and the Division of Economic Paleontologists and Mineralogists in the support and use of the *Journal of Paleontology*. This will test the feasibility of such cooperation:

1. The two societies shall agree to participate on an equal footing in the support and management of the Journal and the Journal shall be the official organ of publication of both societies.

2. The Council of the Paleontological Society shall consult with the officers of the Division of Economic Paleontologists and Mineralogists, and shall prepare for presentation at the next annual meeting of the So-

ciety a detailed plan of cooperative action which can be financed by the Society if the Society increases its dues to $5, and which shall involve a remission of a part of their dues for those members and fellows of the Society who are, or become, members of the Division of Economic Paleontologists and Mineralogists and do not wish to receive two copies of each issue of the Journal.

The committee feels that all the future business relating to this matter should be conducted by the Council of the Society. It therefore requests permission to disband at this time.

Respectfully submitted,

B. F. HOWELL,
Chairman.

It was voted that this report be accepted, and that the Council be authorized to undertake the negotiations with the officers of the Division of Economic Paleontologists and Mineralogists of the American Association of Petroleum Geologists which were recommended by the Committee and be instructed to report to the Society at the next annual meeting.

The chairman of the Service Committee then presented the committee's annual report.

REPORT OF SERVICE COMMITTEE

During the year the committee has continued to render its usual service to members of the Society. It has aided members to obtain positions, has assisted them in finding outlets for publication of the results of their studies, has helped them to secure fossils which they needed and literature which they desired, and has had made for them photographic copies of such literature as could not be made accessible to them in any other way. It has supplied information concerning geologic maps, and has served as a general clearing house for paleontologic and stratigraphic information. It has gathered together and placed at the disposal of the members of the Society information concerning grants, fellowships, assistantships, and other financial aids available to paleontologists.

The committee is making progress with its list of the stratigraphic formations of the world; and it has built up its card file of living paleontologists until this file is believed to be nearly complete, so that the committee is in a position to supply the full names and addresses of most of the workers in our science, and the official positions held and special fields of research being cultivated by the majority of them.

It has been suggested to the committee that it investigate the feasibility of cooperative action by the paleontologists of the world looking to the establishment of an abstract journal to cover the current literature on paleontology, stratigraphy, and sedimentation. The committee recommends that it be authorized to look into this matter and report its findings at the next meeting of the Society.

Respectfully submitted,

B. F. HOWELL,
Chairman.

This report was accepted.

PRESENTATION OF PAPERS

The Society then proceeded to the presentation of papers.

TITLES AND ABSTRACTS

ANNOUNCEMENT OF A NEW LOCALITY OF CAMBRIAN TRILOBITES IN MONTANA

BY C. F. DEISS

(*Abstract*)

The fossil locality lies on the continental divide, north 40 degrees east of Table Mountain, and south 60 degrees east of Pentagon Mountain, in the southeastern part of section 24 of township 25 north, range 12 west. The fossils occur in five beds, which are separated by limestone and calcareous shale beds barren of organic remains. The excellent preservation of the specimens makes them valuable for purposes of investigation and exhibition.

This paper was discussed by Dr. C. E. Resser.

The next paper also recorded the discovery of new Cambrian fossils in North America, and was likewise discussed by Dr. Resser.

CAMBRIAN "PARADOXIDES" FAUNA OF NORTHWESTERN VERMONT

BY B. F. HOWELL

(*Abstract*)

The fauna discovered some years ago in the Saint Albans shale in the vicinity of Saint Albans, Franklin County, Vermont, has proved on study to be a "*Paradoxides*" fauna, as previously announced, but a very peculiar "*Paradoxides*" fauna; for the member of it earlier identified as *Paradoxides* has been shown by recent collecting of better preserved specimens than had before been found to be referable, not to *Paradoxides*, but to *Centropleura* (a genus of the family Paradoxidæ now for the first time recorded from continental North America), while the fauna, as a whole, is small in number of species for a fauna of such late Paradoxidian age as it now appears to be, the faunas of that age in Newfoundland, England, and Sweden having many

species, while the Vermont fauna is known to have only the *Centropleura*, 3 species of Agnostians, 3 other species of trilobites, a brachiopod of the family Obolidæ, a brachiopod of the family Billingsellidæ, and *Eoichthys*, which appears to be a primitive chordate, the oldest one yet discovered.

The third paper recorded Upper Cambrian fossils and Pennsylvanian plants from the Gaspé Peninsula, Quebec.

NEW FAUNA AND FLORA FROM THE PERCÉ AREA, QUEBEC[1]

BY CECIL H. KINDLE

(Abstract)

A well-preserved Upper Cambrian fauna of trilobites, linguloid brachiopods, a sponge and a graptolite has been found in the Percé region. It is of about the same age as the Maryville fauna of the southern Appalachians.

Plants of Pennsylvanian age have been collected from beds considered to belong to the Bonaventure formation, which has hitherto yielded no fossil evidence of its age. These beds were seen to rest on the Gaspé series with an angular unconformity.

The succeeding two papers also dealt with Quebec faunas, which had long puzzled paleontologists. The first described the Philipsburg Series of Quebec, and the second offered a novel explanation of the occurrence of one of its formations.

PHILIPSBURG SERIES OF SOUTHERN QUEBEC[1]

BY H. W. MC GERRIGLE

(Abstract)

The northern Appalachians abound in stratigraphical tangles. One of the most famous of these is concerned with the Lower Paleozoic strata of Philipsburg, Quebec. The strata of the Philipsburg series extend from Highgate Springs, Vermont, northward to Mystic, Quebec, a distance of 25 miles, and are bounded east and west by thrust-faults. On the west they are brought over the "Chazy basin" sediments by the Champlain thrust, and on the east by the Rock River thrust (new name) by which Lower Cambrian dolomites (Milton and Mallett) are brought to lie above them.

The limestones, dolomites, slates and limestone conglomerates of this series extend through the Ozarkian, Canadian and Chazy divisions. Inasmuch as they occur as a slice, roofed and floored by fault-planes, stratigraphic continuity can not be established with more complete or better known sections. The fauna of these beds can not be as satisfactorily compared with that of other beds of equivalent age elsewhere in the Champlain Valley as with that of beds in much more distant parts. The incompleteness of the record is shown partly by the absence of some elements, for instance the Middle Cana-

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dian is absent, and partly by obvious unconformities. One of the latter concerns the relations between the Luke Hill and the Naylor Ledge formations, and may best be explained as the kind that would result from the development of the karst type of topography being covered by sediments which filled hollows, crevices, pipes, etcetera, worn into the older formation. A peculiar apparent reversal of the stratigraphic succession of the fossils has prompted the alternative explanation that the lower member is a cave filling, and therefore younger than the formation which overlies it. Limestone conglomerate beds are common throughout the series, but in the upper part, of Chazy age, they are the dominant feature. Some are autoclastic types, others detrital of uncertain origin.

NAYLOR LEDGE, A MARINE LIMESTONE OF CANADIAN AGE FILLING CAVERNS IN UPPER OZARKIAN FORMATIONS

BY E. O. ULRICH

(Abstract)

The "Naylor ledge"—so called by Dr. H. W. McGerrigle, who is mapping the area adjacent to the town of Philipsburg, Quebec—is included in or between Divisions B-2, 3 of Logan's section of the since much discussed and largely misunderstood Philipsburg series. Beginning with Division A, which is of Lower Ozarkian age and correlatable with the Little Falls dolomite, Logan's section proceeds upward with A-2, A-3, B-1, B-2, and B-3, all of which the present author assigns to successive positions in the Upper Ozarkian, no Middle Ozarkian beds being recognized. B-3 then, is succeeded by B-4 which seems to correspond essentially to the Lower Canadian Tribes Hill formation of New York. Apparently no Middle Canadian deposits occur in the Philipsburg section—that is, no beds corresponding in age to the Beekmantown limestone at its type locality—the Lower Canadian B-4 being succeeded directly by B-5 which, so far as known, consists solely of Upper Canadian limestone that corresponds essentially to Division D of Brainard and Seely's section of the "Calciferous" in the Champlain Valley. Finally B-5 is succeeded by C-1 of undetermined age and this by possibly very late Chazyan or more probably Mohawkian slates with an interesting limestone conglomerate at their base. The boulders of this conglomerate often are filled with well-preserved Upper Ozarkian and Chazyan fossils.

It is the Naylor ledge, with a maximum thickness of 30 feet and its extraordinary content of elsewhere widely separated Upper Ozarkian and Upper Canadian fossils, that is mainly responsible for the faunal incongruities which have hitherto seemed to make a satisfactory correlation and classification of the beds in the Philipsburg section impossible. The present endeavor arises to show that the two wholly different sets of fossils are not so associated as to indicate contemporanity of living but that the Canadian types occur in the matrix, whereas the Ozarkian types are confined to broken blocks and remnants of the roof and walls of a long cavern in B-3 that had been submerged and filled with fossiliferous sediments during Upper Canadian time.

These papers were discussed by Professor T. H. Clark.

The last paper of this session presented new evidence on the systematic position of the graptolites. It was discussed by Professor Cumings.

ARE THE GRAPTOLITES BRYOZOANS?

BY E. O. ULRICH AND R. RUEDEMANN

(*Abstract*)

The graptolites are to this day treated in the textbooks as an appendix, of the order Campanulariæ (Calyptoblastea) of the Hydrozoans, which they closely approach in their habitus. While in the days of Hall and Allman, one felt reasonably sure of this relationship, the conviction has since grown that the graptolites are an entirely extinct class, not closely related to any of the existing orders. On the other hand some forms, as notably species of Mastigograptus, have been recognized by Chapman by the presence of hydrothecæ attached to a hydrocaulus as unmistakable members of the order Calyptoblastea and its family Campanularidæ. These forms are however, not typical graptolites in their structure.

The writers have independently arrived at the conviction that the graptolites, both Dendroidea and Graptoloidea, are more closely related to the Bryozoans than to any other class and probably to be considered as a very early branch of that class that became again extinct. The paper presents the evidence for this view. The evidence consists in the structure of the sicula, which is divided into two parts (prosicula, metasicula) as in the Bryozoans (protœcium and ancestrula), while the primary theca or corallite of the Cnidarians is simple. The budding from the ancestrula takes place as in the Bryozoans not as in the Hydrozoans. The thecæ of the graptolites are bilaterally symmetric, indicating an enclosed zooid with such symmetry, while that of the hydroid polyps is radially symmetric. Primitive Bryozoans and graptolites are alike in their mode of branching. Interior casts of the thecæ of Climacograptus and Glossograptus have been found to show paired muscle impressions, corresponding to those of Bryozoans. Finally dendroid graptolites have been found carrying subspheric appendages on the thecæ, corresponding to the œcia of the Bryozoans.

At 5:25 p. m. the meeting adjourned for the day.

SESSION OF TUESDAY, DECEMBER 30

The Society convened at 10:10 a. m., with President Twenhofel in the chair. The first order of business was the announcement of the election of officers for the coming year.

ELECTION OF OFFICERS

The Secretary announced the results of the balloting for officers, as follows:

OFFICERS FOR 1931

President:

E. R. CUMINGS, Bloomington, Indiana

First Vice-President:

J. J. GALLOWAY, New York City

Second Vice-President:

A. C. NOÉ, Chicago, Illinois

Third Vice-President:

J. W. GIDLEY, Washington, D. C.

Secretary:

B. F. HOWELL, Princeton, New Jersey

Treasurer:

CARL O. DUNBAR, New Haven, Connecticut

Editor:

WALTER GRANGER, New York City

ELECTION TO MEMBERSHIP OF ADDITIONAL NOMINATIONS

The Secretary submitted to the Society the following two additional nominations to membership which had been received and approved by the Council:

NORMAN SHREVE HINCHEY, Department of Geology, Harvard University, Cambridge, Massachusetts. Invertebrate paleontology. Proposed by R. S. Bassler and B. F. Howell.

LEWIS G. WESTGATE, Department of Geology, Ohio Wesleyan University, Delaware, Ohio. Invertebrate paleontology. Proposed by A. F. Foerste, Rudolf Ruedemann, and E. O. Ulrich.

It was voted to suspend the By-Laws and instruct the Secretary to cast the vote of the Society for the election of these two nominees to membership.

APPOINTMENT OF COMMITTEE ON STRATIGRAPHIC PALEONTOLOGY

Professor R. C. Moore informed the Society of a movement to publish a series of volumes on the stratigraphic paleontology of North America, which was being supported by members of the Society and by the Paleontological and Mineralogical Division of the American Association of Petroleum Geologists. He moved that the President be authorized to appoint four members of the Society as the Society's representatives on a joint committee, the other members of which had already been appointed by the Paleontological and Mineralogical Division, said commit-

tee to cooperate in every way possible in this project. This motion was seconded by Dr. F. B. Plummer, and was passed unanimously. The President appointed Messrs. Dunbar, Howell, Resser, and Woodring.

PRESENTATION OF PAPERS

The Society then proceeded to the reading of papers.

The first paper read dealt with problems of the distribution and correlation of certain Ordovician formations of Kentucky. It was discussed by Professor Parks, Dr. Foerste, Dr. Chadwick, Dr. Bassler, and the President.

TITLES AND ABSTRACTS

LEXINGTON-CYNTHIANA-EDEN RELATIONSHIPS IN CENTRAL KENTUCKY

BY ARTHUR C. MC FARLAN

(Abstract)

As herein used the Lexington series is terminated with the Woodburn. South of Lexington the upper members drop out in order and in the southern area of outcrop it is terminated by the middle Benson. The Perryville overlaps from the south and southwest, the Faulconer having widest extent and the other two members showing regressive overlap. The Cynthiana progressively overlaps from the south and southwest across the Perryville and several members of the Lexington. A similar elimination of lower beds up the flank of the arch is shown in the east. The Rogers Gap rests unconformably on the Cynthiana, is developed throughout the Blue Grass region, but is represented mainly by Foerste's upper Eridorthis zone. Older beds occur at the type locality in Scott County and again in the southwestern counties. The Rogers Gap is regarded as Economy.

These relationships are significant in unraveling the early history of the Jessamine dome (Cincinnati arch).

The second paper of this session recorded the discovery of dendroid graptolites, some of them new, in the Silurian rocks of Michigan. It was read by Professor Ehlers, and was discussed by Professor Cumings, Professor Parks, Dr. Ruedemann, and the President.

GRAPTOLITES OF THE NIAGARAN STRATA OF MICHIGAN

BY G. M. EHLERS AND JULIA WILSON BROWN

(Abstract)

This paper reports the discovery of dendroid graptolites in the Niagaran rocks of the Northern Peninsula of Michigan and describes a new genus, *Hippurograptus* and two new species, *Hippurograptus ruedemanni* and *Inocaulus manistiquensis*.

In the next paper the author gave a list of the species, some of them new, found in the Silurian Bainbridge Limestone of Missouri.

FAUNAL LIST FROM THE TYPE SECTION OF THE BAINBRIDGE LIMESTONE, OF MISSOURI

BY JOHN RICE BALL

(*Abstract*)

The type section of the Bainbridge Limestone is in the west bluff of the Mississippi River about 10 miles north of Cape Girardeau, Missouri. Other exposures of the formation, in widely separated outcrops, are between Cape Girardeau and the lower valley of Little Saline Creek, near St. Marys, Missouri. The two localities are about 100 miles apart.

From 1923 to 1926 the writer was engaged in a study of the fauna collected from the limestone in the vicinity of Little Saline Creek. During that time the type section was twice visited. Fossils were not obtained in any abundance until the second visit, when a thin stratum of fossiliferous, shaly limestone was discovered in the type section and in other exposures nearby. More recently the section has been again visited, remeasured, and more material added to the collection.

In a list of about 30 species, 5 have been described previously. Species compared with *Enterolasma waynense* (Safford), *Leptæna rhomboidalis* (Wilckens), and *Diaphorostoma niagarense* Hall are in the fauna. The remaining species apparently are new, and all but five of them seem restricted in their occurrence to the type locality. A new genus of the Auloporidæ is noted both in the strata of the type section as well as in the fauna of the Little Saline Creek Bainbridge. The fauna of the type section, as a whole, shows a preponderance of Mollusca and Trilobita as opposed to the numerous Brachiopoda and Echinodermata of the other locality.

The succeeding paper was a discussion of the use of species of the brachiopod genus, *Atrypa,* as index fossils. It was delivered by Professor Fenton, and was discussed by Dr. Foerste and Dr. Kindle.

ATRYPA AS A HORIZON MARKER

BY CARROLL LANE FENTON AND MILDRED ADAMS FENTON

(*Abstract*)

Brachiopods of the genus *Atrypa*, especially those commonly grouped under the Linnean species *A. reticularis*, constitute a group of fossils of great value for studies in evolution and faunal migration. Their long range, wide distribution, great variation and excellence of preservation make them specially suitable for investigation of minute resemblances and differences.

When these are made the basis for reconsideration of described species (many of which have been disregarded in stratigraphy) and the definition of new groups, *Atrypa* assumes practical importance as a horizon marker and an index of faunal shifts. This is especially true of several species and varieties

in the Devonian of Iowa and adjoining regions, in part described, but not illustrated, by the late C. L. Webster. This material is now being restudied, with the dual purpose of clarifying species, and of furnishing stratigraphers working upon the Devonian of the interior continental province with a set of convenient, reliable and widely distributed horizon markers.

The existence of the Devonian Oriskany fauna at Susquehanna Gap, Pennsylvania, was recorded in the next paper, which was discussed by Dr. Chadwick and Professor Moore.

ORISKANY AT SUSQUEHANNA GAP, PENNSYLVANIA

BY BRADFORD WILLARD

(*Abstract*)

In the early '80s, Claypole reported the presence of an Oriskany fauna at Susquehanna Gap, Pennsylvania. Later, however, he was led to believe that only Hamilton was present. Most geologists who have since studied the section have concluded that the Lower Devonian and certain adjacent beds either never were deposited, or, if laid down at all, have been subsequently faulted out, bringing the Silurian beds into contact with Middle Devonian strata. There is evidence of such faulting; but recent discoveries indicate that the Lower Devonian is represented by a small exposure of Oriskany sandstone carrying a distinctive fauna. This exposure occupies the crest of Little Mountain on the west side of the gap. The patch of Oriskany owes its preservation to having been faulted out of its place in the normal sequence and preserved after adjacent formations, if ever present, have been long since eroded.

The author of the next paper described and illustrated with lantern slides some sedimentary structures found in Devonian beds in New York. The paper was discussed by Dr. Plummer, Dr. Ruedemann, Dr. Foerste, Dr. Chadwick, Mr. Caster, Professor Fenton, and the President.

SEDIMENTARY STRUCTURES IN THE CHEMUNG OF ALLEGANY COUNTY, NEW YORK

BY E. R. ELLER

(*Abstract*)

Sandstones and shaly sandstones of Chemung age, near Alfred, New York, bear numerous markings of the type commonly grouped as "fucoids." Among these are borings like those made by the modern annelid *Arenicola*, others resembling *Arthrophycus* of the Silurian, and still others suggesting the Cincinnatian *Arthraria*. Trails are less common than borings; ripple-marks, of several types, are common.

One shale member contains numerous structures resembling fossils, but provisionally interpreted as slipping of mud nuclei having organic remains as their centers, the process having occurred during sedimentation. These various structures are used to reconstruct a shallow-water, even intertidal marine environment of the late Devonian.

In the succeeding paper the author laid before the Society a plan for the preparation of an illustrated catalogue of North American Devonian fossils.

PROPOSED ILLUSTRATED CATALOGUE OF THE DEVONIAN FOSSILS OF NORTH AMERICA

BY E. M. KINDLE[1]

(*Abstract*)

The number of invertebrate fossils which have been described and identified in North America probably exceeds 50,000. The constantly increasing output of new species accompanied by no improved or more efficient means of access to the type figures and descriptions of the thousands already described suggests that we are in danger of imitating the example of the river which obliterates its trunk channel as a result of the industry of its energetic branches. The object of this paper is to suggest cooperative work which will correct this condition.

It seems most important that some method should be introduced for bringing together in compact usable form the original figures and descriptions of fossils. It is the writer's opinion that the boundaries of a geological system offer the most suitable datum planes for such a synthesis. Within these limits a biological unit of large size, probably the phyllum or order, would seem to afford the most suitable basis on which to assemble the type figures and original descriptions which form the groundwork of paleontology. The grouping of each diagnosis and its figures would be by genera and families in biological order. The illustrations and text would be expected to occupy the two sides of a card or page for each species. The size of card or page recommended is 7¼" by 10", the same as used in "Palæontologia Universalis." In addition to reproducing the original figures and diagnosis for each species the proposed work should give such other figures and observations as later studies and space permit. Index cards with genera and species referred to by serial card numbers would be included in the completion of each phyllum or order. Publication and distribution of each phyllum is proposed as soon as the material for it is ready.

The Geological Survey of Canada is prepared to bear a fair share of the work and expense if other institutions are willing to cooperate in the execution of the plan.

APPOINTMENT OF COMMITTEE ON CATALOGUE OF NORTH AMERICAN FOSSILS

In closing his explanation of this plan Dr. Kindle moved that the Society express its approval of it and authorize the President to appoint a committee to assist in getting it carried out. Dr. Plummer then announced that the Paleontological and Mineralogical Division of the American Association of Petroleum Geologists was planning to get out a similar catalogue covering faunas of a different age. After discussion by

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Professor Moore, Dr. Chadwick and the President, it was agreed that Dr. Kindle's original motion should be divided into two motions, as follows: (1) That the Society heartily indorse the preparation of such illustrated card catalogues of North American fossils; and (2) that the President be authorized to appoint a committee to cooperate with other interested organizations in the preparation and publication of such catalogues, said committee to continue as long as it was needed, and to report annually to the Society. The President appointed Dr. Kindle (chairman), Dr. Foerste, Dr. Howell, and Professor Parks.

At 12:50 p. m. the Society adjourned for luncheon.

PRESENTATION OF PAPERS

TITLES AND ABSTRACTS

At 2:15 the Society convened again, and the reading of papers was resumed, with President Twenhofel in the chair.

The first two papers of this session discussed the evolution of some Late Paleozoic cephalopods.

IMPORTANCE OF THE EVOLUTION OF CERTAIN AMMONOID GENERA IN PENNSYLVANIAN AND PERMIAN STRATIGRAPHY

BY F. B. PLUMMER AND GAYLE SCOTT

(*Abstract*)

The ammonoid genera *Paralegoceras*, *Schistoceras*, *Shumarditcs*, and *Perrinites* constitute a phylogenetic series, which extends from the lowermost beds of the Pennsylvanian to the uppermost beds of the Permian. The species of these genera are easily recognized. They are common as compared with other ammonoids, wide-spread geographically, and stratigraphically restricted to narrow zones, so that they constitute excellent guide fossils. A complete phylogenetic series of this group has been brought together for the first time, criteria for their ready identification developed, and their exact positions in the geologic column indicated.

EVOLUTION OF THE FAMILY PROLECANITIDÆ IN THE NORTH TEXAS PENNSYLVANIAN

BY GAYLE SCOTT AND F. B. PLUMMER

(*Abstract*)

The family Prolecanitidæ is represented in the Texas Pennsylvanian strata by six genera, which range stratigraphically as follows: *Prolecanites* through the Marble Falls stage; *Paraprolecanites* through the Smithwick stage and probably into the basal Strawn; *Pronorites* through the Strawn into the Canyon; *Uddenites* through the Canyon and lower Cisco; and *Parapronorites* in the upper Cisco. In the Wichita beds of the Permian *Parapronorites* is replaced by *Medlicottia*. Only one species of *Daraelites* has been found in the lower Cisco. It is a primitive form, remarkably like *Paraprolecanites* from which *Daraelites* is evidently a direct offshoot. It ranges undoubtedly through the Cisco into the lower Permian. For the first time this complete

phylogenetic series is assembled from consecutive beds of one geological province. Their important species are pointed out, their exact stratigraphic position noted, and their values as index fossils stated.

The next paper described the progress being made in a new field of paleontological investigation.

ECHINOID FRAGMENTS AS INDEX FOSSILS

BY JEROME S. SMISER

(*Abstract*)

A study of Echinoid spines and plates which occur abundantly in many Texas Cretaceous formations, demonstrates that they are very useful index fossils. A number of the common Texas Cretaceous species are being studied with the object of publishing information on them that will enable other paleontologists to identify and use them as time indicators.

The last paper of the session described in detail the Pennsylvanian succession in western Illinois.

PENNSYLVANIAN SECTION IN WESTERN ILLINOIS

BY HAROLD R. WANLESS

(*Abstract*)

The Pennsylvanian section in western Illinois records 22 cycles of sedimentation, 9 of Pottsville, 4 of Carbondale, and 9 of McLeansboro age. The highest bed included in the study is the Shoal Creek limestone, which was one of the beds used by Worthen and his associates about 1870 to divide the upper from the lower Pennsylvanian. The section includes 20 coal beds, 19 horizons of marine fossils and 14 erosional unconformities. Many thin beds—especially of coal, underclay and limestone—are traceable across the greater part of western Illinois, showing that conditions of sedimentation were remarkably uniform over wide areas. The great areal distribution of the 22 cyclic sedimentary suites makes it advantageous to apply geographic names to them, as well as to some of their thicker and more persistent members.

Each bed in the section varies regionally in thickness, and nearly all of them have been found to thin out entirely. The presence of the weak positive Ozark region, which generally supplied but little clastic sediment and yet was submerged during only the greater marine inundations, accounts for the thinning of numerous sandstones and shales toward the south and southwest. Clastic sediment may have come from this area at times, however, for one marine limestone shale section of northern Illinois grades into marine sandy shale and sandstone toward the southwest. Several of the marine limestones thicken toward the south and southwest and grade into shale near the northern border of the coal basin, but the Lonsdale limestone (McLeansboro) attains its maximum thickness (20 + feet) in the northern part of the coal basin and apparently thins out toward the south. The distribution of the limestones indicates that the deeper part of the basin lay generally in southwestern Illinois, but occasionally in northwestern Illinois.

The Pottsville beds attain a maximum thickness of about 180 feet near Rock Island and thin southward to 3 to 10 feet between Quincy and Saint Louis.

The sandstones, shales, limestones and coal beds disappear toward the south and the lesser thickness consists almost entirely of clay which is like the underclay of coal beds.

MEMORIAL OF J. L. TILTON

After the reading of this paper Dr. David White presented a memorial of Professor J. L. Tilton, Fellow of the Society, who died on November 17, 1930.

ANNOUNCEMENT BY DR. MOORE

Dr. Moore then announced to the Society that he had present for examination by the members copies of the *Journal of Paleontology*. He also stated that he would be glad to receive from the members suggestions concerning the proposed volumes on the stratigraphic paleontology of North America which had been discussed at an earlier session.

PRESIDENTIAL ADDRESS "ENVIRONMENT IN SEDIMENTATION AND STRATIGRAPHY," BY W. H. TWENHOFEL

At 3:30 o'clock the Society went into joint session with the Geological Society of America, with President Twenhofel presiding, for the presentation of the presidential address and the reading of stratigraphic papers on the Geological Society's program.

President Twenhofel's address, which was entitled "Environment in sedimentation and stratigraphy," was the first order of business at this session. It is published elsewhere in the present volume.

PRESENTATION OF PAPERS

After the delivery of this address the following three papers were presented. The first was read for the author by Dr. L. S. Russell, and the last was read by title only.

TITLES AND ABSTRACTS

LOWER CRETACEOUS GASTROPLITES CANADENSIS ZONE OF THE NORTHERN CANADIAN INTERIOR

BY F. H. MC LEARN

UPPER PALEOZOIC GLACIATIONS IN AUSTRALIA ALASKA

BY J. B. MERTIE, JR.

UPPER PALEOZOIC GLACIATIONS OF AUSTRALIA

BY T. W. EDGEWORTH DAVIS AND C. A. SÜSSMILCH

At 4:30 the joint meeting adjourned, so that the members might visit the Royal Ontario Museum, arrangements for the inspection of which at that hour had been made by the local committee.

SESSION OF WEDNESDAY, DECEMBER 31

The Society convened again at 10:05 the next morning, with President Twenhofel in the chair, and the reading of papers was resumed.

Examples of bioherms in the Carboniferous rocks of Indiana were described in the first paper of this session, which was discussed by Professor Cumings and Dr. Ruedemann.

PRESENTATION OF PAPERS

TITLES AND ABSTRACTS

BIOHERMS IN THE BORDEN GROUP OF INDIANA

BY PARIS B. STOCKDALE

(*Abstract*)

The chief stratigraphic and faunal perplexities of the upper Borden rocks (Keokuk) of Indiana result from the presence of several irregularly distributed bioherms of different sizes. The bioherms (using the term as defined by Cumings and Shrock, 1928) are mainly within the Floyds Knob formation (Cisco Branch facies) and the Edwardsville formation (Allens Creek facies). They are irregular, lenslike, calcareous masses as much as 70 feet thick and 2 miles in diameter, composed in considerable part of crinoid remains and in a lesser degree of bryozoan fragments. They are completely surrounded by horizontal clastic beds which grade suddenly into the bioherm edges. The masses are not moundlike reef structures with a central core and steeply dipping flank beds peripheral to it. Instead of having been at one time elevated prominences on the sea-bottom, they were formed contemporaneously with the surrounding rocks which were in no way dependent upon nor affected by the colony of organisms. The rocks outside the bioherms are practically barren of fossils. The famous "crinoid beds" at Crawfordsville, Indiana, are within a Borden bioherm. Stratigraphers have been confused as well as perplexed in Indiana, not realizing the situation outlined above. The sudden lateral changes, both lithologic and faunal, have been misinterpreted. Contentions for the presence of deformational structures are unwarranted.

The succeeding paper discussed a genus of gastropods. It was discussed by Professor Moore.

GENUS SOLENISCUS MEEK AND WORTHEN

BY J. BROOKES KNIGHT

(*Abstract*)

Few gastropod genera have been the subject of so much controversy as *Soleniscus* Meek and Worthen and *Sphaerodoma* Keyes. A brief survey of the literature dealing with these genera is presented. Two other genera, *Macrochilina* Bayle and *Bulimorpha* Whitfield are today in common use, although neither seems to be well understood. Type species of each of the four genera are

illustrated. It is pointed out that all four are very closely related and that there are no differences of generic rank between them. *Macrochilina* Bayle, *Bulimorpha* Whitfield and *Sphaerodoma* Keyes are to be regarded as synonyms of *Soleniscus* Meek and Worthen. The supposed differences are of little significance or are due to misinterpretations of imperfect specimens. *Soleniscus* is shown to have possessed a siphon and siphonal notch but no canal. The genus is referred to the Subulitidæ Lindström. It is suggested that the Subulitidæ may be ancestral to the Rachiglossa.

The next paper dealt with the correlation of Triassic formations of the western United States. It was discussed by Dr. Resser.

TRIASSIC CORRELATION

BY A. A. L. MATHEWS

(Abstract)

The Triassic section of the Central Wasatch Mountains is pivotal for correlating the Triassic formations of the Great Basin and adjacent areas. Here the Triassic system is separated from the Permian and the Jurassic systems by unconformities. It includes the Woodside and Pinecrest formations which are Lower Triassic; the Emigration formation which is Middle Triassic, and the Ankareh formation which is assigned to the Upper Triassic. These formations are comformable one with the other representing a continuous, yet oscillatory type of sedimentation. The formational differences are based on the faunas and lithology.

The Woodside shales are placed in the Triassic, because they rest unconformably on the Phosphoria formation and grade up into the overlying Pinecrest without a distinct break. However, on account of its great thickness and the stratigraphic position above of the first fossiliferous limestone, the *Meekoceras* bed, the Woodside may represent the post-Permian pre-Triassic interval.

The Thaynes "group" is divided into the Pinecrest and Emigration formations on faunal basis. The Pinecrest formation contains fossils of the world-wide *Meekoceras*, *Owenites*, *Anasibirites*, *Tirolites* and *Columbites* zones. The *Anasibirites* beds are correlated with the same beds in Spitzbergen, northern Siberia and Timor, and are the equivalent of a part of the *Hungarites* shales, Ceratite sandstone and limestone, and the upper part of the *Hedenstroemia* beds of southern Asia. It is not certain that rocks of the Pinecrest formation occur in the Park City district, consequently it is considered lower than the original Thaynes. The Emigration formation contains a Middle Triassic fauna including *Xenodiscus bittneri* and *Daonella dubia*. It is considered the equivalent of the lower and middle Middle Triassic of the western part of the Great Basin and probably the upper part of the Portneuf limestone of southeastern Idaho.

The Ankareh formation overlies the Emigration conformably, but is separated from the Nugget by a well-defined basal conglomerate. It is considered Upper Triassic and the equivalent of the Timothy sandstone of southeastern

Idaho. (See Mesozoic stratigraphy of the central Wasatch Mountains, Oberlin College Laboratory Bulletin, new series, number 1, 1931.)

The fourth paper was an ecological one. In the absence of the author it was read by title.

INTERPRETATION OF THE MARINE ENVIRONMENT OF THE UPPER CRETACEOUS OF THE PRAIRIE PROVINCES BASED ON THE FORAMINIFERAL FAUNAS

BY R. T. D. WICKENDEN [1]

(*Abstract*)

A sequence of foraminiferal faunas grading from simple arenaceous to calcareous is repeated at least three times in the Upper Cretaceous of the Prairie Provinces. This is interpreted as repeated changes from brackish water to more typical marine conditions.

The next paper dealt with a proposed program of research in paleobiology. It was discussed by Professor Cumings, Professor Field, and Dr. Kindle.

STUDIES IN PALEOBIOLOGY

BY CARROLL LANE FENTON AND MILDRED ADAMS FENTON

(*Abstract*)

Studies carried on at the Puget Sound Biological Station during the summer of 1930 have contributed data of value in ecologic interpretation of fossil faunas and associated sedimentary structures. Intertidal brachiopods were found in a region of cold water, strong tidal scour and conglomerate accumulation, some of these brachiopods (*Terebratalia*) occupying pools reached only by high waves. The rôle of annelids and plants (*Zostera*) in production of markings resembling fucoids was studied, and additional evidence was found that many markings commonly attributed to annelids were produced by snails and clams.

In connection with these studies, and others on fossil faunas, a cooperative program of research in paleobiology is proposed. Such a program may bring together a file of information to be placed at the disposal of paleontologists interested, and by stressing ecology rather than adaptation (the field emphasized in much European work) may aid the stratigrapher and sedimentationist as well as the paleontologist.

The succeeding paper presented further evidence of a warm interglacial period in eastern North America. It was discussed by Dr. Willard, Dr. Chadwick, and Dr. Ruedemann.

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FURTHER EVIDENCE OF A WARM INTERGLACIAL PERIOD ON THE ATLANTIC COAST

BY HORACE G. RICHARDS

(*Abstract*)

It was reported last year that a study of the fauna of the most recent of the Pleistocene formations of New Jersey, the Cape May, has suggested an interglacial rather than a glacial origin as formerly supposed.

Further collecting has been carried on in New Jersey. The filling-in of many of the marshes along the sea coast for real-estate development has revealed a large fauna. It seems significant that the deeper the dredging (in the Cape May formation), the warmer is the climate indicated by the fossils.

Collecting has been continued south into Delaware, Maryland, Virginia and North Carolina. Here, as in New Jersey, the fauna of the most recent Pleistocene terrace indicates a climate slightly warmer than that of the present. This is further evidence that the formation is of interglacial age.

An attempt has been made to trace the shoreline of New Jersey at the time of the deposition of the Cape May formation.

The next paper of this session recorded the finding of five associated specimens of Devonian fishes in Pennsylvania. It was discussed by Dr. Willard.

BOTHRIOLEPIS SLAB FROM NORTHEAST PENNSYLVANIA

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

Chance discovery of a slab of red "Catskill" shale containing remains of five entire individuals of *Bothriolepis*, presumably *B. minor* Leidy, in Bradford County near Wyalusing, Pennsylvania, has given much fuller information concerning this species. The specimen will be exhibited, together with some other "fish" remains from that area.

The succeeding paper also described Devonian fishes, in this case from Canada. It was discussed by Dr. Kindle, Dr. Chadwick, and Professor Howell.

DEVONIAN FISHES OF EASTERN CANADA

BY LORIS S. RUSSELL[1]

(*Abstract*)

A general discussion of the Devonian fish faunas of Campbellton, New Brunswick, and Scaumenac Bay, Quebec, illustrated by original restorations.

The next paper, which had been prepared by Professor Tilton before his death for presentation at this meeting, was read by Professor Galpin. It was discussed by Professor Carman.

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PERMIAN VERTEBRATE TRACKS IN WEST VIRGINIA

BY JOHN L. TILTON

(*Abstract*)

The paper describes, illustrates and names two specimens of vertebrate tracks that have been found in the Waynesburg sandstone (Permian) of West Virginia. For one of these new forms the name *Dimetrodon berea* is proposed, referring to the locality where the specimen was found. For the other form the name *Baropus waynesburgensis* is proposed, from the beds in which the imprints occur. The various measurements are given and comparisons made with specimens at the National Museum, Washington, described by C. W. Gilmore.

The paper also calls attention to the relation of *Baropus waynesburgensis* to *B. coconinoensis* in the Coconino sandstone of the Grand Canyon, and of *Dimetrodon berea* to *D. gigas* in the Permian of Texas, evidence bearing on correlation.

The succeeding three papers recorded the discovery of tracks and bones of Mesozoic reptiles in western Canada. In the absence of the author the first paper was read by Mr. Sternberg.

ENVIRONMENT OF DINOSAUR TRACKS IN THE PEACE RIVER CANYON

BY F. H. MC LEARN [1]

(*Abstract*)

The tracks occur in thinbedded sandstone and dark shale in the Lower Cretaceous coal-bearing Gething member of the Bullhead Mountain formation. The sandstone layers have ripple-marks, chiefly of the symmetrical (wave) type. The shale beds have mud cracks. They are interpreted as the deposits of shallow flood-plain lakes whose bottoms were exposed as mud flats at times of low water. It was across these flats that the tracks were made.

LOWER CRETACEOUS DINOSAUR TRACKS IN PEACE RIVER CANYON, BRITISH COLUMBIA

BY C. M. STERNBERG [1]

(*Abstract*)

The most northerly record of dinosaur tracks in North America, and the second record for Canada, is that from Peace River canyon (near parallel 56) in coal-bearing beds of Lower Cretaceous age. McLearn and Berry have correlated these beds with the Lower Blairmore.

Most of the tracks are preserved in ripple-marked sandstone or clay ironstone. They are preserved at many horizons throughout a vertical thickness of 400 feet. The longest trackway is over 100 feet in length and contains 33 tracks. Over 400 individual tracks, ranging from 6 to 25 inches in length, were observed. These appear to represent 5 species, 4 of which were bipedal,

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tridactyle, digitigrade dinosaurs. Moderately sharp claws are suggested in most of these. The fifth species represents a quadruped showing 4 toes on the hind feet and 3 on the front. This animal was doubtless herbivorous and may represent an early ceratopsian.

No marks of the tail or the front feet of the bipedal forms were observed. Not even a fragment of bone could be found.

TWO ICHTHYOSAUR LOCALITIES IN BRITISH COLUMBIA

BY C. M. STERNBERG[1]

(*Abstract*)

Moderately complete skeletons of ichthyosaurs have been discovered at two localities in British Columbia. The first was collected from the Fernie formation, near Fernie, British Columbia, and was presented to the National Museum of Canada by Mr. W. R. Wilson. Several partly complete skeletons of ichthyosaurs are preserved, in rocks of Triassic age, on the upper part of Peace River, near the mouth of Nabesche River. Ten individuals, all of which are badly scattered and in very hard black limestone, were observed. Some of these are very large. Two specimens were collected by the Geological Survey of Canada in 1930.

At 12:50 the Society adjourned for luncheon, convening again at 2:00, with President Twenhofel presiding.

RESOLUTION OF THANKS

Professor Galloway moved, and it was voted, to instruct the Secretary to express to the Society's host, the University of Toronto, its thanks for the University's hospitality.

PRESENTATION OF PAPERS

The presentation of papers was then resumed. The first paper, which dealt with one of the huge birds which roamed over the western United States in early Tertiary times, was read by title, as the author was not present.

TITLES AND ABSTRACTS

DIATRYMA, THE GIANT EOCENE BIRD

BY EDWARD L. TROXELL

(*Abstract*)

Discussion of known species, restorations of type specimens, relationship to other ancient and modern birds. New data on the skeleton, adaptive characters, a reconstruction in the flesh.

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In the two papers which followed accounts were given of recent discoveries of fossil mammals and associated human artifacts in the southwestern United States. They were discussed by Mr. Sternberg.

QUATERNARY ANTELOPES OF SHELTER CAVE, NEW MEXICO

BY CHESTER STOCK

(*Abstract*)

Shelter Cave is located in the Organ Mountains, 38 miles north of El Paso. This site was explored during the past summer by the Los Angeles Museum. While remains of a number of Quaternary mammals are known from the deposits in this cave, attention is directed particularly to the occurrence of two, possibly three, antelope types. The genus *Tetrameryx* is well represented in the collection. Skull and skeleton materials of this form display a number of characters significant from the standpoints of preservation, age, variation and relationships. Definitely associated with *Tetrameryx* is the small antelope *Capromeryx*. Possibly belonging in the fauna or perhaps to a later stage is *Antilocapra*.

EXPLORATION OF GYPSUM CAVE, NEVADA

BY CHESTER STOCK

(*Abstract*)

Gypsum Cave, a large limestone cavern located approximately 20 miles northeast of Las Vegas in southern Nevada, has been explored during the past year by the Southwest Museum and the California Institute. Unusually well preserved remains of the ground sloth *Nothrotherium* occur in the deposits in association with materials of the horse, mountain sheep and camel. Typical specimens will be shown.

Artifacts found in the deposits in close proximity to the bones of extinct mammals and the nature of the preservation of some of the latter types raise the important questions of contemporaneity and age.

The succeeding paper discussed newly discovered evidence relating to the age of the ancient human implements and accompanying mammals found in the western United States in recent years. It was read by title in the absence of the author.

ANCIENT ARTIFACTS AND ASSOCIATED FOSSILS FROM EASTERN COLORADO

BY HAROLD J. COOK

(*Abstract*)

In Yuma County, Colorado, there occur beds in the high plateaus that contain mammoth, bison and other fossils—and also contain numerous "Folsom type" artifacts of the splendid, yet ancient type which we reported from New Mexico. These fossils and artifacts appear to be contemporaneous; and a comprehensive study of the geology offers a splendid opportunity to help date the "Folsom culture artifacts."

The final paper of the meeting, the only one on a paleobotanical subject, discussed certain fossil floras found in California. It was also read by title, as the author was not present.

PLEISTOCENE FLORAS OF THE SAN FRANCISCO BAY REGION

BY HERBERT L. MASON

(Abstract)

Deposits containing highly carbonaceous fossil plants are common in the San Francisco Bay region. They vary from estuarine along Tomales Bay to lenses of peat on the San Francisco peninsula. An invertebrate fauna is associated with the plant fossils in the estuarine deposits, and fragmentary vertebrate remains have been found at several localities. The flora is composed of modern species, dominated by Monterey pine and Douglas fir, representing an association now restricted to discontinuous coastal areas in California, and indicating no great change in climate. Correlation with other Pleistocene floras in California, together with evidence from associated vertebrate and invertebrate faunas, indicates a Lower and an Upper Pleistocene horizon in these deposits.

The Society adjourned at 2:50.

MINUTES OF THE MEETING OF THE PACIFIC COAST BRANCH OF THE PALEONTOLOGICAL SOCIETY

The regular annual meeting of the Pacific Coast Branch of the Paleontological Society was held at the University of California, Berkeley, on Saturday, February 22, 1930, in affiliation with the Cordilleran Section of the Geological Society of America and the Le Conte Geological Club. President W. D. Matthew presided. The minutes, prepared by the Secretary, Dr. G. Dallas Hanna, are given herewith:

ELECTION OF OFFICERS

The following officers of the Section were elected for the year

President:
CHESTER STOCK, California Institute of Technology

Secretary:
G. DALLAS HANNA, California Academy of Sciences

PRESENTATION OF PAPERS

The Branch convened at 9:30 a. m. The following papers were presented during the morning session:

TITLES AND ABSTRACTS

IMPORTANCE OF THE GENOTYPE IN TAXONOMY

BY U. S. GRANT, IV

(*Abstract*)

The importance of a strict adherence to the International Rules of Zoological Nomenclature is emphasized. All reviews, revisions and discussions of genera and subgenera should be guided first of all by knowledge of the characters of the type species called genotypes. All generic and subgeneric descriptions represent merely some author's conception of the genus which may be inaccurate or misleading due to: (1) being based upon a species or several species not including, and not sufficiently similar to, the genotype; or (2) to failure to describe characters of the genotype which prove to be of great systematic value. Where classification has been based upon some species erroneously believed to be genotypes much needless confusion and shifting of names has been necessary to bring the nomenclature into conformity with the International Code. Article 30 of the Code, governing the designation of type species of genera is discussed in order to show its applications, and examples are presented for illustration. Genotype designation by the method call "type by elimination" is shown to have no place in modern systematics.

COMSTOCK FLORA OF OREGON

BY ETHEL I. SANBORN

(*Abstract*)

The Comstock flora has been secured from two locations in the railroad cut north of Comstock, Oregon. These beds have yielded a flora of approximately 35 species, which show a close relationship to the Clarno flora from both Cherry Creek in the John Day Basin and from the Crooked River; and also with the small flora from the Arago beds in Coos County. The most abundant leaves in the collections are *Cinnamomum dilleri* and *Aralia whitneyi*. With the possible exception of *Laurus princeps*, there is no species which is found in the Goshen flora.

CRITICAL OBSERVATION ON THE PHYLOGENY OF THE RHINOCEROSES

BY W. D. MATTHEW

(*Abstract*)

Studies of a series of skulls and skeleton material of the rhinoceros, *Aphelops*, from the Texas Pliocene have made necessary various comparisons with the later Tertiary American rhinoceroses and with those of the Old World. There is much diversity of opinion among authorities as to the relationship and phylogeny of the Old World rhinoceroses and their affinity to the American genera. In my view insufficient weight has been given to the generally recognized Holarctic origin of the family, the living members all in the outlying

regions, being persistently primitive survivors, little changed from ancestral stages which inhabited Holarctica in the Miocene and Pliocene. In the accompanying diagram the principal living and extinct types are arranged in accordance with the outstanding distinctive characters in horns, tusks, and hypsodonty of the cheek teeth. The tentative phyletic arrangement indicated is based upon these and various other distinctive characters.

MIOCENE MAMMALIAN FAUNA FROM SOUTHEASTERN OREGON

BY C. LEWIS GAZIN

(*Abstract*)

The fossiliferous beds occur in a small basin which drains south and east toward the Owyhee River, Malheur County, Oregon. The locality is about three miles northeast of Skull Springs, southeast of Cottonwood Table, and about twenty-eight miles south of Harper. The deposits are principally ash and apparently lie in basins formed on the upper surface of rhyolite flows; they seem to be older than the surrounding basic rim-rock.

The fauna consists in part of a rather large assemblage of carnivores and rodents, including amphicyons, mustelids, a hemicyon, squirrels, aplondont and mylagaulid rodents, and pocket mice. Among the squirrels three new species are recorded. The remainder of the fauna consists of brachydont and hypsondont horses, a rhinoceros, a peccary, oreodonts and cervids. The fauna as a whole is not a plains assemblage but indicates rather a semi-humid or perhaps forest environment, probably associated with the fresh-water bodies known to exist in this region during the Miocene.

The age of the assemblage is close to that of the Mascall in the John Day region of eastern Oregon, and to the age of the Virgin Valley fauna of northwestern Nevada. A close time relation is also seen to exist with the Pawnee Creek Miocene of Colorado and with the Lower Snake Creek beds of Nebraska.

OCCURRENCE AND RELATIONSHIP OF GALEODEA IN THE OLIGOCENE OF WASHINGTON

BY NELLIE MAY TEGLAND

(*Abstract*)

The large gastropod which appears in great abundance in Oligocene horizons on the Pacific slope, heretofore referred to the genus *Eudolium* seemingly without ancestors in Eocene deposits of the same area, has been correctly referred to the genus *Galeodea* which is plentifully represented in the earlier horizons. A phylogenetic series has been traced from the Upper Eocene species through Oligocene horizons to the Miocene representatives of the genus. Five new species are recognized from the Oligocene of Washington and these differentiated from the "*Eudolium*" *petrosum* originally described from the Astoria Miocene. One fact brought out is that the period of maximum development of the genus *Galeodea* was in Oligocene time and not during the Eocene epoch as hitherto supposed.

NEW INSECTIVORES FROM THE LOWER PALEOCENE

BY T. EMMETT REYNOLDS

(*Abstract*)

During the past field season two skull fragments with associated lower jaws were collected from the Puerco, or lower member of the Paleocene, San Juan basin of New Mexico. The molars are of a very primitive type approaching a zalambdodont pattern. This is the first insectivore material from the lower Puerco. A second skull with associated lower jaw was collected but a short distance from the first, but with teeth of a more advanced type.

It is thought that these specimens add much to the interesting history of the ancient group and add new evidence as to the nature of the fauna of Paleocene times.

LARGER FORAMINIFERA

BY T. WAYLAND VAUGHN

(*Abstract*)

1. Exhibition of and comments on a piece of Ocala limestone from near Marianna on which there are very fine specimens of *Discocyclina* (*Asterocylina*) *americana*, *mariannensis*, and *georgiana*, and *Lepidocyclina fragilis*.

2. Lantern slide illustrations of peculiar species of *Discocylina* from Mexico and of *Actinosiphon*, *Orbitocyclina*, *Pseudorbitoides*, and a few species of *Lepidocyclina* to show structural features.

The Branch adjourned for luncheon, and reconvened at 2:00, when the reading of papers was continued, as follows:

CAMBRIAN ALGAL REEFS OF TEXAS

BY A. H. DEEN

(*Abstract*)

Masses of algal limestone occur in the Willberns shales of Upper Cambrian age in Mason County, Texas. In exposed cliffs these bodies, varying in size from an inch to a hundred or more feet in diameter, have the appearance of concretions. Frequently several have coalesced to form a "reef." The larger ones consist of cylindrical or oyoid columns which may reach forty or more feet in length and two feet in diameter. In horizontal cross-section they resemble Cryptozoon proliferum.

Shale layers are frequently discontinuous at the edges of the masses because of the rapid accumulation of the algoid material, but sooner or later the entire colony was covered by the deposition of glauconitic shale.

These limestone masses and "reefs" play an important rôle in the topography because of their resistance to erosion. Not infrequently they cap the highest hills in the area where these Cambrian sediments outcrop.

Lantern slides were used to illustrate this and the next two papers.

CEPHALOPODS OF THE GENUS ATURIA FROM WESTERN NORTH AMERICA

BY HUBERT G. SCHENCK

(*Abstract*)

The genotype or *Aturia* Bronn, 1838, is *Nautilus Aturi* Basterot, by virtual tautonymy and subsequent designation. The subgenus *Sphenaturia* proposed by von Ihering in 1921 is not accepted since it is based upon a misconception of the genotype. Representatives of the section *Aturoidea* of Vredenburg have not been available, hence the validity of the section cannot be questioned. Twenty-four "species" of this cosmopolitan genus have been reported from marine formations ranging in age from Upper Cretaceous to Lower Pliocene, but on the Pacific Coast of North America specimens have not been found in rocks younger than Temblor (Middle) Miocene. The preparation of the review necessitated certain changes and additions to the descriptive terminology, as well as a study of shell structure and mode of living of Recent nautiloids. Sexual dimorphism and the importance of ontogenetic stages are thought to be significant in the erection of species, as will be shown in the discussion of the taxonomy and relationships of the West Coast forms.

AGE AND AFFINITIES OF THE LAMAR VALLEY FLORA

BY CHARLES B. READ

(*Abstract*)

The Lamar Valley flora of the Yellowstone Park occurs throughout a series of basic breccias 5,000 feet thick, and is abundantly represented by both leaves and woods. Regarded as Upper Miocene, evidence is at hand to suggest that it is much older—either Lower Oligocene or Upper Eocene.

CORALS OF THE GENUE CARYOPHYLLIA FROM CALIFORNIA

BY ERNEST H. QUAYLE

(*Abstract*)

The genotype of *Caryaphyllia* Lamarck, 1801, is *Madrepora cyathus* Solander and Ellis by subsequent designation, 1836. The genus *Caryophyllia* is represented in California by four species, all of which are present in the Pleistocene formations of San Pedro. Three of them are Recent, one is found near San Diego, one in Monterey Bay, and the other along the Alaskan Coast. This latter is specifically identical with specimens from the "Pliocene" of Deadman Island.

Only the central lathe of the columella in *Caryophyllia* is *essential*, i. e., rises from the center of the basal disc. The outer lathes, usually six in the first set, and twelve in the outer set set, are derived from the inner margins of the septa and pali, and are, therefore, *parietal*. Occasionally two essential lathes arise instead of one.

This paper was read by title.

OCCURRENCE OF HUMAN REMAINS IN CONKLING CAVERN, NEW MEXICO

BY CHESTER STOCK

(*Abstract*)

Conkling Cavern (Bishop's Cap Cave) occurs in a belt of Carboniferous limestone on the flanks of the Organ Mts., New Mexico, 43 miles by road from El Paso. Excavations conducted by the Los Angeles Museum reveal a cave of several chambers, irregular in shape and containing a series of deposits whose total thickness approaches 33 feet. Scattered human remains were found in the deposits, principally at a level 15 feet or more below the original floor of the cave. There is no evidence in the occurrence of this material to indicate a burial.

From the cave deposits were procured bones and teeth of approximately 20 types of mammals representing extinct and living species. The ground sloth (*Nothrotherium*), the camel (*Tanupolama*), horse, antelope, bison, a large wolf (*Ænocyon?*), coyote, several of the smaller carnivores and rodents are included in the assemblage.

In the course of the early excavations Mr. R. P. Conkling, discoverer of the cave, records the finding of human remains on the same stratigraphic level with the camel and ground sloth. Contemporaneity of man and some elements of the mammalian fauna appears reasonably certain.

UPPER EOCENE ORBITOIDAL FORAMINIFERA FROM THE SANTA YNEZ RANGE, CALIFORNIA

BY W. P. WOODRING

(*Abstract*)

A soft limestone exposed on the south slope of the western Santa Ynez Range near Sudden, at a locality discovered by W. S. W. Kew and H. L. Driver, yields well-preserved specimens of a small *Discocyclina* and a small *Actinocyclina*. The same foraminifera are found in hard limestone farther west on the north slop of the range overlooking Jalama Creek and they also correspond to the species recorded by H. G. Schenck from the Sierra Blanca limestone of the upper Santa Ynez River basin. Elsewhere in America *Actinocyclina* is confined to deposits of upper Eocene age and in the absence of evidence to the contrary the conclusion that these beds are upper Eocene seems justified, as Schenck suggested for the Sierra Blanca limestone. The limestones in the western part of the range are reef lenses in deposits that are regarded as representing a heretofore unrecognized division of the Eocene younger than the Tejon formation. It is suggested that they are of the same age as beds in the vicinity of Gaviota Pass, which, according to the work of A. Clark and L. C. Hookway, carry a distinct Eocene fauna and are younger than deposits carrying a Tejon fauna, but this still is a matter of inference.

RECENT GULF COAST FORAMINIFERA OF TEXAS AND LOUISIANA

BY M. M. KORNFELD

(*Abstract*)

The Neogene and Quaternary formations of the West Gulf Coastal Plain contain foraminifera in assemblages similar to those of the present strand-line. Since a study of these Recent forms, which descended from Tertiary ancestors, should throw light upon problems encountered during a study of samples from well borings, the writer has examined foraminifera collected in 1928 and 1929 from eighty shore stations along the coast from the Rio Grande to the Mississippi River. These foraminifera are adapted to a shallow-water subtropical environment. An outstanding characteristic of the fauna is the abundance of *Rotalia beccarii* (Linnaeus) d'Orbigny and several species of *Elphidium*. These are distinguished by marked exogenous deposits. Various genera of the Miliolidae are also present, whereas arenaceous forms are rare. In California, for comparison, similar assemblages of *Rotalia* and *Elphidium* are abundant in Recent bays and estuaries, as well as in certain late Tertiary beds in the San Joaquin Valley.

This paper was illustrated with lantern slides.

EOCENE ALGAE AND STELLATE ORBITOIDS FROM THE SANTA YNEZ RANGE, CALIFORNIA

BY RICHARD N. NELSON AND HUBERT G. SCHENCK

(*Abstract*)

Independent collectors have obtained samples from lenticular bodies of limestone from two new localities in the vicinity of Jalama Creek, a few miles north of Point Conception, Santa Barbara County, California. The algae and foraminifera in this material suggest that at least one of the limestones may be correlated with the Sierra Blanc limestones of the San Rafael Mountains, which also contain a stellate *Discocyclina*. Comparisons have been made with the other algal limestones previously reported by the writers and with that from the Martinez (Paleocene) formation of the Santa Monica Mountains, California, known prior to the note by Gilian (Bull. Amer. Assoc. Pet. Geol., vol. 13, p. 1485, 1929).

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*SINCLAIR, WILLIAM J., Princeton University, Princeton, N. J.
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*STANTON, T. W., U. S. Geological Survey, Washington, D. C.
*STAUFFER, CLINTON R., University of Minnesota, Minneapolis, Minn.
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STETSON, HENRY C., Museum of Comparative Zoology, Cambridge, Mass.
STEWART, GRACE A., Department of Geology, Ohio State University, Columbus, Ohio.
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STOCKDALE, PARIS B., Ohio State University, Columbus, Ohio.
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*SWARTZ, JOEL H., University of North Carolina, Chapel Hill, N. C.
*TALBOT, MIGNON, Mt. Holyoke College, South Hadley, Mass.
TEGLAND, NELLIE M., Bacon Hall, University of California, Berkeley, Calif.
TESTER, ALLAN, Department of Geology, University of Iowa, Iowa City, Iowa.
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THOMPSON, ALBERT, American Museum of Natural History, New York City.
*THORPE, MALCOLM R., Peabody Museum, Yale University, New Haven, Conn.
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*TROXELL, EDWARD L., Trinity College, Hartford, Conn.
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*ULRICH, EDWARD O., U. S. Geological Survey, Washington, D. C.
UNGER, CLAUDE E., Pottsville, Pa.
UPSON, M. E., Gulf Production Co. of Texas, Fort Worth, Texas.
*VAN TUYL, FRANCIS M., Colorado School of Mines, Golden, Colo.
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*WHITE, DAVID, U. S. Geological Survey, Washington, D. C.
*WHITNEY, F. L., University of Texas, Austin, Texas.
WIEDEY, LIONEL W., c/o International Petroleum Co., Ltd., Negritos, Peru.
*WIELAND, G. R., Yale University, New Haven, Conn.
WILLARD, BRADFORD, Topographic and Geologic Survey of Pennsylvania, Harrisburg, Pa.
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WINTON, W. M., Texas Christian University, Fort Worth, Texas.
WOOD, ALBERT ELMER, Cape May Court House, Cape May, N. J.
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*WOODFORD, ALFRED O., Pomona College, Claremont, Calif.
*WOODRING, WENDELL P., U. S. Geological Survey, Washington, D. C.

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BUNTON, PAUL B., 402 Transportation Building, Washington, D. C.

BURGESS, ANNE EDITH, 221 Grant Avenue, Highland Park, New Brunswick, N. J.

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COLBERT, EDWIN HARRIS, 500 Riverside Drive, New York City.

ELLER, E. R., 114 Tillinghast Place, Buffalo, N. Y.

ELLIS, BROOKS FLEMING, 85 Waller Avenue, White Plains, N. Y.

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FRITZ, MADELEINE ALBERTA, 2 Spadina Road, Toronto, Ontario.

GILBOE, JOHN DANIEL, 2216 Park Way, Bakersfield, Calif.

GILDERSLEEVE, BENJAMIN, Damascus, Va.

HEMINWAY, CAROLINA ELLA, 150 Elm Street, Northampton, Mass.

HESSE, CURTIS J., Bacon Hall, University of California, Berkeley, Calif.

HINCHEY, NORMAN SHREVE, Department of Geology, Harvard University, Cambridge, Mass.

HUSBAND, RACHEL A., American Museum of Natural History, New York City.

HUTCHINS, FORBES MEREDITH, 3524 Ontario Avenue, Montreal, Quebec.

JONES, ALICE JEANETTE, Box 671, Mount Holyoke College, Northampton, Mass.

KINSEY, CHARLES ALBERT, Belgrade, Mont.

KORNFELD, MOSES MARION, Atlantic Oil Producing Company, 906 Central Building, Wichita, Kans.

MACNEIL, DONALD JONATHAN, Department of Geology, Princeton University, Princeton, N. J.

MCKEE, EDWIN DINWIDDIE, Grand Canyon, Ariz.

MOLES, EDWIN JENNEY, JR., 52 Holder Hall, Princeton, N. J.

PATMONT, LOUIS RICHARD, 520 Rose Court, Santa Rosa, Calif.

RICHARDS, HORACE GARDINER, 509 Woodland Terrace, Philadelphia, Pa.

SCHEVILL, WILLIAM E., Museum of Comparative Zoology, Cambridge, Mass.

SHROCK, ROBERT R., 205 Science Hall, Madison, Wis.

SIEGFRIEDT, JOHN C. F., Red Lodge, Mont.

SWEET, SIDNEY RICHMOND, Bridgeport, Nebr.

VANDER HOOF, V. L., Bacon Hall, University of California, Berkeley, Calif.

VAN PELT, HERBERTA LILLIAN, 6043 St. Lawrence Avenue, Chicago, Ill.

WELLS, DANA, 633 Spruce Street, Morgantown, W. Va.

WESTGATE, LEWIS G., Ohio Wesleyan University, Delaware, Ohio.

WHIPPLE, G. LESLIE, Bacon Hall, University of California, Berkeley, Calif.

WICKENDEN, ROBERT THOMAS DAUBIGNY, Geological Survey of Canada, Ottawa, Ontario.

NEW CORRESPONDENTS

MR. FREDERICK CHAPMAN, National Museum of Victoria, Melbourne, Victoria.

DR. HISAKATSU YABE, Tohoku Imperial University, Sendai, Japan.

CORRESPONDENTS DECEASED

BUCKMAN, S. S., Esq. Died Feb. 26, 1929.
DÉPERET, PROF. CHARLES. Died May 17, 1929.
KOKEN, E. Died Nov. 24, 1912.
NATHORST, DR. A. C. Died Jan. 20, 1921.
POMPECKJ, DR. J. F. Died July 8, 1930.
WOODWARD, DR. H. Died Sept. 6, 1921.

FELLOWS AND MEMBERS DECEASED

*AMI, HENRY M. Died Jan. 4, 1931.
ARMSTRONG, EDWIN J. Died Jan. 21, 1925.
*BARRELL, JOSEPH. Died May 4, 1919.
BELANSKI, CHARLES H. Died Apr. 30, 1929.
BILLINGS, W. R. Died Mar. 1, 1920.
BOSTWICK, THOMAS A. Died Apr., 1923.
*CALVIN, SAMUEL. Died Apr. 17, 1911.
*CLARK, WM. B. Died July 27, 1917.
*CLARKE, JOHN M. Died May 29, 1925.
*CROOK, A. R. Died May 30, 1930.
CROZEL, GEORGE. Died Oct., 1921.
DALL, W. H. Died Mar. 27, 1927.
*DEAN, BASHFORD. Died Dec. 6, 1928.
*DERBY, ORVILLE A. Died Nov. 27, 1915.
*EASTMAN, CHAS. R. Died Sept. 27, 1918.
*FONTAINE, WM. M. Died Apr. 30, 1913.
GILL, THEODORE N. Died Sept. 25, 1914.
GORDON, ROBERT H. Died May 10, 1910.
HAMLIN, HOMER. Died July, 1920.
HARPER, GEORGE W. Died Aug. 19, 1918.
HAWVER, J. C. Died May 15, 1914.
*KNOWLTON, FRANK H. Died Nov. 21, 1926.
*LAMBE, L. M. Died Mar. 12, 1919.
*LEE, WILLIS T. Died June 17, 1926.
LUSK, RALPH G. Died July 27, 1927.
*LUTHER, D. D. Died Dec. 17, 1923.
LYON, VICTOR W. Died Aug. 17, 1919.
MARTIN, BRUCE. Died Dec. 23, 1919.
MATTHEW, GEO. F. Died Apr. 17, 1923.
MATTHEW, W. D. Died Sept. 24, 1930.
MOODY, W. L. Died Oct. 9, 1920.
*PROSSER, C. S. Died Sept. 11, 1916.
*SEELY, HENRY M. Died May 4, 1917.
*SPRINGER, FRANK. Died Sept. 22, 1927.
TELLER, EDGAR E. Died July 19, 1923.
*THOMAS, A. O. Died Jan. 13, 1931.
*TILTON, J. L. Died Nov. 17, 1930.
*TWITCHELL, M. W. Died Apr. 8, 1927.
*VAN INGEN, GILBERT. Died July 7, 1925.
*VOGDES, ANTHONY W. Died Feb. 8, 1923.
*WALCOTT, CHARLES D. Died Feb. 9, 1927.
WARING, CHARLES A. Died Nov. 5, 1918.
*WELLER, STUART. Died Aug. 5, 1927.
*WILLIAMS, HENRY S. Died July 31, 1918.
WILLISTON, S. W. Died Aug. 30, 1918.
WILSON, HERRICK E. Died Jan. 24, 1925.
WHITTAKER, EDW. J. Died Sept. 14, 1924.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 42, PP. 385-392 MARCH 31, 1931
PROCEEDINGS OF THE MINERALOGICAL SOCIETY

PROCEEDINGS OF THE ELEVENTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA, HELD AT TORONTO, CANADA, DECEMBER 29 AND 30, 1930.

FRANK R. VAN HORN, *Secretary*

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SESSION OF MONDAY AFTERNOON, DECEMBER 29

The Mineralogical Society of America held its eleventh annual meeting on December 29 and 30, 1930, in conjunction with the Geological Society of America, at the University of Toronto, Toronto, Canada. On Monday, December 29, at 2 p. m., in Room 56, Mining Building, President Herbert E. Merwin called the regular annual meeting to order. On motion of the Secretary, the reading of the minutes of the last annual meeting was dispensed with, in view of the fact that they have been printed on pages 109-122 of volume 15, number 3, of the *American Mineralogist*.

ELECTION OF OFFICERS AND FELLOWS

The Secretary announced that 177 ballots had unanimously been cast for the officers as nominated by the Council. For Fellows there was a unanimous vote of 81 ballots in the affirmative. All officers and Fellows as nominated were declared elected. The officers for 1931 are the following:

President, Alexander H. Phillips
Princeton University, Princeton, New Jersey

Vice-President, William F. Foshag
U. S. National Museum, Washington, D. C.

Secretary, Frank R. Van Horn
Case School of Applied Science, Cleveland, Ohio

Treasurer, Waldemar T. Schaller
U. S. Geological Survey, Washington, D. C.

Editor, Walter F. Hunt
University of Michigan, Ann Arbor, Michigan

Councilor 1931-1934, William S. Bayley
University of Illinois, Urbana, Illinois

The Fellows elected follow:

MR. HARRY BERMAN, Assistant in the Mineralogical Museum, Harvard University, Cambridge, Massachusetts.

DR. PAUL NIGGLI, Professor of Petrography and Mineralogy, Eidgenössische Technische Hochschule, Zurich, Switzerland.

DR. PAUL RAMDOHR, Professor of Mineralogy and Economic Geology, Aachen, Germany.

REPORT OF THE SECRETARY

The Secretary reports that the roll of the Society now comprises 114 Fellows and 274 members in good standing, which is exactly the same as last year. Three Fellows, A. R. Crook, L. Mc.I. Luquer, F. A. Wilder and one member, W. E. Mumford, have died during the year. In addition to the 388 Fellows and members, there are 214 subscribers, a gain of 15 for the year. A total of 602 paid copies of the Journal are mailed monthly, an increase of 15 over last year. Actually during the past year 3 Fellows, 53 members and 26 subscribers, a total of 82, were added to the list, but deaths, resignations, with nonpayment of dues and subscriptions, have reduced the mailing list by 67 names. The Secretary wishes to acknowl-

edge the efficiency of the Treasurer, Professor A. B. Peck, and express his regret that he no longer feels able to serve in that capacity. Ninety-five Fellows, members and guests registered at the meetings. There were 29 scientific papers presented at the various sessions of the Society.

REPORT OF THE TREASURER

The Treasurer, A. B. Peck, read his report which showed a very favorable balance. On motion, the report was accepted and ordered filed. On motion, an Auditing Committee composed of nonmembers of the Council, was appointed by the President. This committee, consisting of L. S. Ramsdell, C. B. Slawson and N. L. Bowen, reported at a later session that they found the books of the Treasurer correct, and that they had also inspected the securities owned by the Society.

REPORT OF THE EDITOR

The Editor, W. F. Hunt, read his report which, on motion, was accepted and ordered filed. An abstract of the report follows:

The accomplishments of the *American Mineralogist* for 1930 must be considered as highly satisfactory since on only one other occasion has a volume of approximately the same size been issued. During the year 47 leading articles covering every phase of mineralogy were received from 47 individuals representing 25 different universities, research bureaus and technical laboratories. Forty-two of the articles came from contributors within the States while five were received from Canada. Aside from the leading articles the current volume contains 14 additional shorter contributions, 14 book reviews, proceedings of five different mineralogical societies, 31 abstracts of new species described in foreign journals and numerous brief items of interest. The complete volume contains 582 pages with 156 illustrations. One unique feature of volume 15 is the unusually large number of new minerals described in detail for the first time—eleven new minerals, of which eight are phosphates. This establishes a record for any one-year period.

REPORT OF THE NEW COMMITTEE ON NOMENCLATURE AND CLASSIFICATION OF MINERALS

This committee consists of W. T. Schaller, chairman; W. F. Foshag, E. S. Larsen, T. L. Walker, E. T. Wherry and A. N. Winchell. J. F. Schairer was added by President Merwin to insure more cooperation with the authors working on a new edition of Dana's System of Mineralogy. The chairman reported that the committee had held two long sessions and

had unanimously reached some conclusions and had left others in abeyance for future consultation with a similar committee of the Mineralogical Society of Great Britain and Ireland. The committee asked that it be continued, which was moved and carried.

REPORT OF THE REPRESENTATIVE ON THE NATIONAL RESEARCH COUNCIL

The representative of the Society, W. T. Schaller, gave a brief summary of the work of the National Research Council and some of its committees during the year which were of interest to the Society. These were the committees on Potash-Soda Feldspar, Clay Minerals, Measurement of Geologic Time by Atomic Disintegration, and Processes of Ore Deposition.

NEW BUSINESS

It was moved and carried that a committee be appointed to investigate the question of a medal to stimulate interest in the Society. The President appointed E. H. Kraus, A. N. Winchell and E. S. Larsen.

It was moved and carried that a committee be appointed to cooperate with the Secretary of the XVI International Geological Congress which meets in Washington in 1932, along the lines of Mineralogy and Petrology. The President appointed W. F. Foshag, W. T. Schaller and J. F. Schairer.

In view of a suggestion in the Editor's report, it was moved and carried that 100 separates be given to authors of articles in the *American Mineralogist* instead of 50 as at present.

MEMORIAL BIOGRAPHIES

In view of the fact that none of the authors of memorial biographies were present, and also that the articles will be printed in the *American Mineralogist*, it was moved and carried that they be read by title. They were as follows:

Memorial of A. R. Crook [died May 30, 1930], by A. J. Walcott.
Memorial of L. McI. Luquer [died January 30, 1930], by P. F. Kerr.
Memorial of F. A. Wilder [died March 8, 1930], by J. J. Runner.

PRESENTATION OF PAPERS

At 2:50 p.m., there being no further business, the presentation of papers was taken up according to program, as follows:

CHRYSOCOLLA GROUP

BY W. T. SCHALLER

NEW LIGHT ON THE ROLE OF WATER IN SIMPLE AMPHIBOLES

BY E. POSNJAK AND N. L. BOWEN

Fe_2O_3-Fe_3O_4 SOLID SOLUTIONS

BY J. W. GREIG, S. POSNJAK AND H. E. MERWIN

CRYSTALLIZATION IN THE SYSTEM Na_2O-Fe_2O_3-SiO_2

BY J. F. SCHAIRER

At 3:57 p.m., the Society adjourned to attend the joint session with the Geological Society.

JOINT SESSION WITH GEOLOGICAL SOCIETY OF AMERICA, DECEMBER 29

The Mineralogical Society of America held a joint session with the Geological Society of America at 4 p.m., Monday, December 29, in Room 22, Mining Building. Doctor Herbert E. Merwin, of the Mineralogical Society, delivered his presidential address, "Some associations of ore minerals," which will be published in the March number of the *American Mineralogist*. During the remainder of the afternoon, papers of the Geological Society of a mineralogical and petrographical nature were presented, with H. E. Merwin in the chair. The joint session adjourned at 5:25 p.m.

Session of Tuesday Morning, December 30

At 9:20 a.m., President Merwin called the second session of the Society to order, and the reading of scientific papers proceeded according to program.

PRESENTATION OF PAPERS

CRYSTAL STRUCTURE OF POTASSIUM DITHIONATE, $K_2S_2O_6$

BY M. L. HUGGINS AND G. O. FRANK

PRINCIPLES DETERMINING THE ARRANGEMENTS OF ATOMS AND IONS IN CRYSTALS

BY M. L. HUGGINS

EUHEDRAL QUARTZ CRYSTALS AND QUARTZ ROSETTES FROM SALT DOME, TEXAS CAP ROCK ANHYDRITE

BY L. S. BROWN

AMMONIOBORITE, A NEW MINERAL

BY W. T. SCHALLER

CRYSTALS OF SULVANITE

BY W. T. SCHALLER

CLARKEITE, A NEW URANIUM MINERAL

BY C. S. ROSS, E. P. HENDERSON AND E. POSNJAK

CASTANITE, A BASIC FERRIC SULFATE FROM KNOXVILLE, CALIFORNIA

BY A. F. ROGERS

NEW SULFATE OF POTASH AND IRON FROM CALIFORNIA

BY W. F. FOSHAG

CONTACT METAMORPHISM OF THE PRE-CAMBRIAN FORMATIONS NEAR MELLEN, WISCONSIN

BY STEPHEN RICHARZ

PERSISTENCE OF FELDSPAR IN BEACH SANDS

BY J. H. C. MARTENS

PARAGENETIC CLASSIFICATION OF THE MAGNET COVE MINERALS

BY K. K. LANDES

ZEBRA ROCK FROM WESTERN AUSTRALIA

BY D. W. TRAINER, JR.

GRANITE PEGMATITE FROM SALT CREEK, TULARE COUNTY, CALIFORNIA

BY A. F. ROGERS

PHILOSOPHIC CLASSIFICATION OF MINERAL STRUCTURES

BY A. C. LANE

CRYSTALLOGRAPHY OF KORNELITE

BY W. T. SCHALLER

At 12:10 p.m., Dr. W. F. Hunt moved to adjourn until 2 p.m. This action was explained as being due to the fact that few people were in attendance and also that the program could probably be completed early in the afternoon. The motion was seconded and carried.

Session of Tuesday Afternoon, December 30

At 2:10 p.m., President Merwin called the third session of the Society to order, and resumed the reading of papers according to program.

PRESENTATION OF PAPERS

EXAMPLE OF CROSSED AXIAL DISPERSION

BY GILBERT GREENWOOD

NOMENCLATURE OF GEOMETRICAL CRYSTALLOGRAPHY

BY A. F. ROGERS

STRUCTURAL CRYSTALLOGRAPHY

BY A. F. ROGERS

IDENTIFICATION OF PSILOMELANE BY MEANS OF ITS PHYSICAL PROPERTIES

BY L. S. RAMSDELL

SIMPLE DEVICE FOR THE APPLICATION OF DIFFERENTIAL PRESSURE IN EXPERIMENTS ON HYDROTHERMAL MINERAL ALTERATION

BY J. W. GRUNER

OPTICAL AND CHEMICAL NOTES ON THE TRANSFORMATION OF GREEN TO BROWN HORNBLENDE

BY WM. A. P. GRAHAM

SPHERULITE OPTICS

BY H. W. MORSE AND J. D. H. DONNAY

COMPOSITION OF THE AMPHIBOLES

BY E. S. LARSEN AND HARRY BERMAN

FURTHER STUDIES IN THE AMPHIBOLE GROUP

BY A. N. WINCHELL

FERVANITE, A NEW VANADIUM MINERAL FROM COLORADO

BY E. P. HENDERSON AND F. L. HESS

VOTE OF THANKS

The last paper was finished at 4:07 p.m., after which Dr. W. J. McCaughey moved that the thanks of the Society be extended to the authorities of the University of Toronto, to the local committee and to Mrs. D. A. Dunlap for their kindness and hospitality. This was seconded by Dr. A. F. Rogers and unanimously adopted by a rising vote, after which the Society adjourned.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 42, PP. 393-406 MARCH 31, 1931

GEOLOGY AS AN AGENT IN HUMAN WELFARE[1]

PRESIDENTIAL ADDRESS BY R. A. F. PENROSE, JR.

(Read before the Geological Society December 29, 1930)

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INTRODUCTION

From the earliest times in human history the economic and industrial activities of man have been changing the natural features of the earth's surface in many different ways, such as by constructing dams, by diverting the courses of rivers, by connecting oceans and seas with canals, by tunnels, by mining, by draining oil from the rocks containing it, and in many other ways modifying the natural course of geologic processes.

Much has been written concerning this material influence of man on the earth, but the opposite effect, that is, the influence of the earth on man, has received much less attention; and yet from primitive times it has been active. It seems proper therefore to note the action of geologic phenomena on man throughout the ages in which he has existed. These influences may be either beneficial or detrimental to man's welfare; they may advance his physical and mental development and his grasp on life, or they may form obstacles in his progress, and at times threaten his very existence. Though periods of slow development and even times of retrogression have occurred in human history, yet throughout the ages as a whole the change, especially in mentality, has been forward, and indicates that man has been able to adapt himself to such geologic surroundings as he has had to meet.

[1] Manuscript received by the Secretary of the Society January 9, 1931.

Relation of Geology to primitive Man

The earliest well authenticated remains of human life as yet known are in late geologic times, in the Pleistocene Epoch, during the last Great Ice Age, and in what is known in prehistoric archeology as the Paleolithic Period of the Stone Age; but man or his predecessors may have been active among the animal life of the earth before those times.[2] The Paeolithic Period was characterized by the use of flint, chert, jasper and other materials of a flinty character, susceptible to being chipped into sharp-edged weapons or fashioned into other utensils. Ivory and bone were also used in a similar way, while various hard rocks, such as granitic materials, were often used for axes and heavy weapons.

Paleolithic man was a dweller in caves and other shelters formed by geologic action and is often referred to as the cave man. Had it not been for these retreats together with his flint and stone weapons, he might not have found protection from the elements and from his enemies in the form of other animals; and hence some of the early human races might have disappeared on account of the lack of assistance offered by geologic agencies.

In the caves together with the remains of Paleolithic man occur in different places those of the reindeer, the mammoth, the cave bear, the fox, the wild horse, the bison and other animals, mostly of forms now extinct. Drawings and paintings on the walls of caverns, as well as ivory carvings, indicate a degree of art among these primitive men which suggests an advance from a possible former less developed condition.

Previous to the Paleolithic times, in the Prepaleolithic or Eolithic Period, flint and other fragments chipped in a manner to suggest a crude human handicraft, are often found in alluvial or subaerial deposits. Such materials frequently occur in formations much older than the Pleistocene and even in the Pliocene Epoch or earlier times. Many archeologists doubt their connection with mankind, while others believe that some of them at least are true artifacts. However this may be, it is a recognized fact that some undoubted artifacts occur in older geologic environments than those in which human bones have yet been found, and this suggests that the bones of remote primitive man who made them have decayed

[2] The present discussion relates to only distinctly human primates, as distinguished from what in remote times may have partaken of the character of both the anthropoid ape and man, such as the remains of the so-called ape-man (*Pithecanthropus erectus*) found near Trinil in Java.

and disappeared, while his more resistant flint and stone implements remain intact.

Among the oldest human remains as yet known is a fragment of a lower jaw found in an alluvial deposit at Mauer near Heidelberg, Germany (*Homo heidelbergensis*) and supposed to belong to the beginning of the Pleistocene Epoch. This fragment as well as parts of a human skull found near Piltdown in Sussex, England (*Eoanthropus dawsoni*), are usually accepted as the two most ancient evidences of human life as yet discovered. A more complete skull, but of vastly later date in the Pleistocene Epoch, was discovered in a cave in the valley of Neanderthal near Düsseldorf, Germany, and represents what is known as the Neanderthal man (*Homo neanderthalensis*). Somewhat later a complete skeleton of a similar human being was found in a cave near le Moustier, France.

Human remains and implements resembling those found with the Neanderthal or Mousterian man, have also been discovered in many other places in Europe, North Africa, Arabia, Asia Minor, China and elsewhere. He seems to have thrived particularly during periods of recession in the several alternating advances and retreats of the Glacial Period, when the milder climate favored his development. He did not make pottery and did not use metals; he had no cattle or other domestic herds; he was a hunter living by the chase.

The Neanderthal man was succeeded in the latter part of the Paleolithic Period and the beginning of the Neolithic Period of the archeologist by other races among whom the flint and other stone implements derived from geologic sources were more carefully finished and polished than in the preceding period. The Aurignacian, Solutréan and Magdalenian man thrived in these times. Copper implements made their appearance. Man began to emerge from caves, except where convenience made them desirable, he built shelters in the open, made pottery, and gathered together herds of cattle. Signs of civilization began to appear, and with it came the more and more modern races of man (*Homo sapiens*).

The caves which gave protection to primitive man depended largely on the character of the geologic formations which permitted the creation of these and other shelters. They were formed in many ways, but mostly in calcareous rocks through which surface waters impregnated with carbonic acid gas from the decay of vegetation percolated into cracks in the rocks, and by their solvent action created openings varying from small cavities to larger caves, and frequently to great caverns. They are common throughout the world wherever limestone or other calcareous rocks exist. They often provided the early man not only with shelter

but with water, for many such caves have springs or running streams within them; and sometimes they supplied him with food in the form of other animals which also had sought refuge there.

Caves which may at times have afforded shelter have also been formed by the beating of the sea on the rocks adjacent to the coast. This has occurred not only in limestone but in sandstone, granite, basalt and other materials which during the ages have succumbed in spots to the constant wear of the waters. In later times some of these coastal areas have been elevated, and the caves are found high up on the land. Other less frequent geologic influences may also have provided similar refuges for primitive man.

In North America caves and great caverns occur in many places, but they do not seem to have been used permanently as dwellings to the same extent as in Europe and Asia. The human remains sometimes found in them seem to be there as a result of accident or temporary necessity throughout bygone ages, but do not show signs of permanent habitation. This may be due to the fact that the ancestors of the American Indian when they migrated to this continent had reached a stage in civilization that enabled them to construct their own habitations without resorting to the primitive shelters of caves.

The cliff dwellers in the southwestern part of the United States and in Mexico represented in a certain way a class of cave man, inasmuch as their habitat was in the rocky cliffs of canyons, but they were of comparatively recent date, and in no way connected with the cave man of the Stone Age of Europe and Asia. Many archeologists believe that they date back only from several hundred to a few thousand years. They seem to have been an early part of the great family of Pueblo tribes which now inhabit the open country in the same neighborhood as are found the remnants of the old cliff dwellings.

These dwellings were sometimes caves in the faces of the cliffs, or were artificial structures built by man on shelves of rock in similar localities, or were combinations of both. Some of the caves were enlarged by man into capacious dwellings or even underground villages. Flint instruments and utensils are numerous, as well as bows and arrows, pottery, baskets, personal ornaments and other decorations, many of them not unlike those made by the modern Pueblo tribes.

The cliff dwellings were used not only as shelters, but also for the storage of corn and other products of the field, as well as for religious ceremonies and for burial places. They are mostly high up on the cliffs, several hundred or a thousand feet above the lowlands, though some are

down near the water level. The cliffs themselves consist of a great variety of rocks, including sandstone, various calcareous materials, shale, basalt and eruptive tufa.

Though we thus see that the cliff man had no relationship with the cave man of primitive times, yet his preservation, or at least his protection, was due to similar geologic conditions of environment, which supplied not only shelter but flint and other materials for his utensils, and rock for the buttressing of his habitations.

Effect of Volcanoes on Man

Volcanic action has always had a marked effect on man and his destiny. It has generally been of a tragic character, due to the sudden upheaval of volcanic materials and the destruction of human life and property, but often its after-effects have been beneficial to human welfare in returning desirable materials from great depths to the surface of the earth.

Volcanoes occur in many parts of the world, being particularly abundant in the regions of the Pacific Ocean. In the Malay Archipelago they are so numerous and enormous that it has often been called "the rookery of volcanoes," while elsewhere through the Pacific regions they are abundant not only on the land, but especially on the sea bottom. In Mexico, Central and South America, in the West Indies, in Iceland, Europe and many other parts of the world they are among nature's most spectacular manifestations of unrest.

Mount Vesuvius has been studied in its eruptions for almost 2,000 years, and hence its history gives us more enlightenment on the effect of volcanic action on man than other regions where eruptions have only been investigated in later periods. Until the first century of the Christian era Mount Vesuvius had been considered an extinct volcano and had been inactive during historic times, so that the neighborhood with its salubrious climate and wonderful soil had become thickly populated.

About the year 63 A.D. numerous slight earthquake shocks were felt in the vicinity of Mount Vesuvius and these gradually increased until without warning, in the year 79 A.D., Mount Vesuvius itself broke out in a more violent eruption than it has ever developed in later times. The materials thrown out consisted mostly of volcanic ashes and dense clouds of steam and gases. The ashes overwhelmed the cities of Pompeii and Herculaneum and other places, and so sudden was the upheaval that many of the inhabitants were suffocated and buried in the volcanic materials. It is probable, however, that the loss of life was not so great as at first believed, and we know from the letters of Pliny the Younger, that a large

part of the population fled to the sea at the first dreadful shock of the outburst, and thus escaped the annihilation which befell those who were more tardy.

The uncle of Piny, known as Pliny the Elder, a noted naturalist of his time, was then in command of the Roman fleet in the waters of that region. As soon as the volcanic outburst began he put into shore to rescue the refugees, but was overcome by fumes and ashes and died like many of his countrymen. The younger Pliny describes the occurrence in a letter to the Roman historian Tacitus, and tells how he himself refused at first to leave the shore because he wished to save his uncle, but when convinced that this was impossible, he led his mother and others out of the danger zone.

In other regions than Mount Vesuvius even greater catastrophes have befallen humanity as the result of volcanic action. In Iceland, in the year 1783, a tremendous eruption of the volcano Skaptar is said to have destroyed about one-fifth of the population of the island by the direct results of the outbreak and the famine which ensued. Even more loss of life and property has occurred in the great volcanic eruptions in the Malay Archipelago and other places, but their historic records are less definite than in the countries which have been longer studied.

In 1772 the volcano Papandayang in the Malay Archipelago broke out with such force that the upper 4,000 feet of the cone are said to have been blown off and thrown broadcast, destroying over 40 villages. The most enormous eruption known, however, was that of the volcano Tamboro on Sambowa Island, near Java, in 1815, when actually many cubic miles of material are estimated to have been thrown into the air, destroying life and property throughout the region, while the clouds of ashes and gases obscured the sky for hundreds of miles distant. In 1883 the volcano Krakatoa in the Strait of Sunda, between Sumatra and Java, broke out in an enormous eruption throwing ashes to great heights and over vast areas. The atmospheric disturbance was felt around the whole world, and the seismic waves accompanying the eruption overwhelmed the coasts of Java and Sumatra, causing great loss of life. The volcanoes of the Hawaiian Islands are frequently in active eruption, and the spectacular outbreak of Kilauea in 1924 is well known to all of us, while Mauna Loa, the greatest of all Hawaiian volcanoes in size, is noted for the frequency and vastness of its lava flows.

The foregoing remarks have described only the disastrous effects of volcanic action on mankind; but there is another and more cheerful side to the problem, and that is, the beneficial effects. It has often been asked

why the agricultural populations around Mount Vesuvius and Mount Etna, after being driven from their abodes and after their villages and vineyards had been destroyed, have almost always returned when an eruption subsided. One reason for this is the natural reluctance of people, particularly in Europe, to forsake the salubrious climate and rich soil which have in previous days rendered them prosperous and happy; but a particular reason is that the materials composing volcanic ash and lava are remarkably rich in fertilizing substances, such as phosphates and various other salts of calcium, sodium, potassium, iron and other elements important to vigorous plant growth. In the warm, moist climate of southern Italy and Sicily the volcanic ash and lava rapidly disintegrate and the fertilizing constituents are set free, thus creating a soil often far richer than the one that had preceded it, which may have been more or less exhausted by continuous cultivation for generations.

The disintegration of lava on Mount Etna is often artificialy assisted by encouraging the growth of a large native cactus which rapidly takes root in the cracks and fissures of the rock and by its expansive power tends to disintegrate it and hasten its decay. On both Mount Etna and Mount Vesuvius the stone quarries worked in the hard lava form an additional source of income to the owners of the surrounding vineyards. Hence we find that the inhabitants of these volcanic regions flee in terror when eruptions occur and destroy all they own, but respond to the lure of the old home and return full of hope, with a knowledge that future prosperity awaits them.

Volcanic eruptions also restore enormous quantities of carbonic gas to the atmosphere, and thus replace that which has been absorbed by plant life and certain animal organisms. They also raise from deep-seated sources large quantities of water, often in the form of vapor, and thus return it to the surface.

In early historic times volcanic eruptions were regarded as something mysterious and uncanny, suggesting that the end of the world was approaching, or that the gods were angry, or that something altogether mysterious had occurred. In the flight of the population from Pompeii during the eruption of 79 A.D., the general outcry of the people was that there were no more gods, for they and the earth and its inhabitants were headed direct for everlasting ruin. In later times, however, man began to investigate volcanic eruptions in a more self-composed manner, and the modern scientist who has devoted himself to volcanism has shown that they are purely local manifestations which can even in some cases be anticipated.

Effect of Earthquakes on Man

The influence of earthquakes as a geologic agent affecting man is very marked, not only by the great destruction of life and property, but by the mental effect of shock and terror which often deeply impresses itself on the minds of those who escape with their lives.

They occur in many parts of the world, in Europe, Asia, Africa, America and elsewhere, but are most notable in the region of the Pacific Ocean. Though they attract particular attention on the land, yet a far larger number occur on the sea-floors, especially in the Pacific, the West Indies region of the Atlantic and elsewhere. These submarine earthquakes often give rise to immense waves, popularly known as tidal waves, which, however, have no connection with tides. They are caused by sudden changes in the level of the sea-bottom, which either force vast volumes of water upward, or let similar quantities downward, in either case transmitting their motion to the surface and thus creating immense waves. The so-called tidal waves therefore are well termed seismic waves, as indicating their origin in seismic disturbances. They often roll onto the adjacent land, causing as much devastation as if the earthquake had occurred on shore, and sometimes more.

The destructive aspect of earthquakes has been manifested in many great seismic movements which have become records of horror in the history of human fatality. Among some of those familiar to most of us may be mentioned the great earthquake at Lisbon in Portugal in 1755 followed by an overwhelming seismic wave whereby the city was reduced to ruins, with the loss of 30,000 or 40,000 people. In Japan numerous earthquakes have occurred, and in fact most of that country is in a constant condition of greater or less vibration. The last of its great outbreaks was the terrible catastrophe of 1923 at Tokyo and Yokohama, in which 100,000 lives are supposed to have been lost. Almost equally disastrous earthquakes have occurred in many other places.

In regions closer to our home may be mentioned the series of earthquakes in 1811 in the Mississippi Valley, about 50 miles below where the Ohio River enters the Mississippi. The principal disturbances were near New Madrid, Missouri, but others also occurred on the east side of the river in Kentucky and Tennessee. In places the land sunk many feet, and for brief periods the Mississippi River actually flowed backward in its course as a result of the collapse of its bed. The disastrous earthquake at Charleston, South Carolina, in 1886, is well known to many of

us, and both it and the Mississippi earthquake were in regions where earth movements of such magnitude did not seem probable.

The great earthquake in California on April 18, 1906, was of all others in America in historic times preeminently notable in its extent. The movement followed for some 270 miles or more a great fracture zone extending along the coast. It was mostly horizontal and the displacement varied from a few inches to over 20 feet. Fences, fields and roads were thrown out of line. In San Francisco the water mains were broken, and a large part of the city was burned from lack of water to quell the fires which started in many different places. Here, as often in other earthquake disasters, the loss of life and property was due not so much to the earth movements as to the fires which were started as a result of them.

It has generally been found that the greatest destruction by earthquakes occurs in soft ground, either of an alluvial character, or such as is made in cities by filling up hollows with debris of various kinds, and known as made ground; while on the higher land, particularly on the rocky parts, catastrophes are much less severe. This is doubtless due to the fact that the amplitude of vibration in an earthquake movement is much less in solid rock than in loose material, so that a structure built on a mountainside may be only damaged, while one built below on soft material may be reduced to ruins. This feature was particularly noticeable in the earthquake at San Francisco in 1906. The principal destruction was on the water front along the Bay of San Francisco, while higher up on the hills where residences were built on rocky foundations the earthquake itself produced much less damage, but the fire which followed the earthquake spread death and destruction in both the lower and the upper parts of the city.

The earthquake at Valparaiso, Chile, on August 16, 1906, only a few months after the California disaster, extended along the coast for some miles; and as in San Francisco, the greatest destruction was caused in the soft or made ground along the water front of the bay, while the structures on the hills back from the lower city were much less injured. The lower city was almost completely destroyed, and when the speaker visited it shortly after the earthquake, efforts to restore it had only begun. The estimate of the people killed varied from 4,000 to 7,000.

On a hill but little above the lower city in Valparaiso, a large cemetery was located where graves were thrown open and great numbers of coffins hurled down the hillsides into the streets below, causing fear and panic among the people, who thought the time of resurrection had come. The keeper of the cemetery is said to have gone insane at the sight. Rain was

falling in deluges at the time, with much thunder and lightning, so that the scene was indeed terrifying to everyone, and even at the time of the visit of the speaker but few people would discuss the situation which had left such a lasting impression on their memories.

Mention might be made of many other earthquakes which have taken their toll of life and property, and have had a lasting and painful mental effect on those who survived; but just as in volcanic eruptions, the scientific study of their nature has to some extent abated the feeling of terror and helplessness which they inspire. In earthquake regions man is learning to reduce the danger by selecting proper locations for buildings, suitable materials for their construction, and above all, by endeavoring to provide water supplies that may survive earthquake shocks and thus be used to quell the fires which cause more loss of life and property than the seismic disturbances themselves.

Effect of alluvial Deposits on Migrations of Man

The erosion by rivers has a twofold effect on man, one beneficial because it creates vast areas of alluvial soil available for agricultural purposes, and the other harmful because it creates floods, often accompanied by great destruction of life and property.

In the upper course of a river the current may be swift enough to keep the channel clear of the lighter sediments, but in its lower parts the waters may move more sluggishly as they pass through a lower country before they enter the sea; and hence the sediments instead of being entirely carried on sink partly to the bottom of the river. This constant accumulation of silt gradually raises the level of the river bed and the waters overflow, often spreading over vast areas and depositing a rich alluvial soil wonderfully adapted to agricultural purposes.

Hence from prehistoric times large communities have grown up along the lower parts of many rivers, especially on the broad deltas at their mouths, and thus these alluvial regions have often been important geologic influences in the early migrations of man. Among such regions in Europe may be mentioned the thickly inhabited deltas of the River Po, the Danube, the Rhone and other streams, while the enormous delta lands in Africa and Asia are preeminent in size and historic interest, notably those of the Nile in Africa, and of the Euphrates, the Tigris, the Indus, the Ganges and the Brahmaputra in India. The great alluvial region in ancient Mesopotamia and Babylonia, lying between the Euphrates and the Tigris rivers, was once so widely populated that it was known as the cradle of civilization. It supported many ancient cities, such as

Nineveh, Babylon, Nippur, Ur, Bagdad and numerous other once prosperous communities.

One of the greatest delta lands in the world is that of the Yellow River, Hoang-ho, in eastern China, which from remote ages has supported a vast population.

Though the streams which have formed great alluvial plains have at times brought happiness and prosperity to the inhabitants, yet they have only too often also brought great loss of life and property. Where agricultural communities and other settlements have grown up embankments have been made to restrain the river floods; but as the sediments continue to settle and the river beds continue to rise, the embankments have to be built higher and higher. Ultimately in time of high water the embankments may be broken down and the surrounding lowlands may be subjected to great floods. Hence the efforts of man to confine rivers to definite channels and thus to reclaim for agricultural purposes the fertile floodplains which were nature's provision to accommodate the excess water when the rivers rose, have often been accompanied by great catastrophes.

When the floods subside, however, the breaches in the embankments are often repaired, the people return and agriculture proceeds as formerly. This process of reconstruction is often repeated time after time as new breaches occur, and thus a somewhat precarious but highly lucrative agriculture is continued often for ages.

The frequent floods in the lower Mississippi River illustrate such occurrences. The first embankments or levees near New Orleans, about 150 years ago, were some 4 feet in height, but as the river bottom rose they had to be built up several times that high. The levees have been extended northward up the Mississippi River for many hundreds of miles and throughout this great distance numerous breaks frequently occur. Hence the disastrous floods and loss of life and property in the Mississippi Valley which shock the country at frequent intervals.

In other lands many similar results have attended attempts to confine rivers to narrow channels and prevent them from overflowing their natural floodplains. The River Po in Italy has been embanked for so many centuries that its bottom is many feet higher than the surrounding lowlands, and disastrous floods have at times followed breaks along its course. In China the Hoang-ho has often broken through its embankments with enormous loss of life, and many of us can remember the great flood of 1887 along this river, in which more than a million, perhaps several millions, of people were lost.

In ancient times in other parts of the world, many of the old embankments were abandoned and are now found only in a condition of decay. Their history of disaster is lost in the vagueness of bygone ages.

Influence of mineral and other geologic Products on Man

The mineral products of the earth have probably been of more material benefit to mankind than any other single geologic influence. Even the men of the Stone Age were careful to open quarries where the best flints for their implements could be found. The character of different flints was closely inspected, and in fact this material was in many ways to primitive man what iron and steel are to modern man.

During the latter part of the Stone Age and following it, weapons and utensils of copper made their appearance among prehistoric man. Still later came the use of bronze and this was followed by the Iron Age, in which a greater impetus to human welfare than in all previous times started and still continues to be a dominant factor in man's progress.

The beginning of the use of copper, bronze and even iron is involved in greater or less obscurity in different localities, and doubtless the use of each was dominant at different times in different parts of the world. In fact flint or stone implements were often used by backward races after others had long since begun to make implements of metals. In Neolithic times copper began to be used before flint was discarded. The advent of the use of metals, however, has always supplied the necessary element for rapid human progress; more things, greater things and quicker things were accomplished by the use of metals than by the flint and stone implements of primitive man.

The modern age includes both the use of iron and of many other metals, so that we exist in a time which though preeminently one of iron, is also marked by the extensive use of copper, lead, zinc, gold, silver, nickel, aluminum, tin and many other metals, while to these must be added the numerous alloys, such as brass and bronze, which are made from them. Hence the present times are characterized more by human handicraft in fabricating metals than by the use of any one of them, and may well be termed preeminently the age of manufacture.

To the metals now used must be added other materials of a geologic character which have advanced human welfare, such as natural fuels, including coal, petroleum and gas, without which the efforts of modern man and his accomplishments would have been much retarded. We must also consider the stone for structural and ornamental purposes, and many other geologic materials which have affected human welfare, such

as soils, springs and water supply, and the rapidly increasing and enormously important use of waterfalls and other moving waters in generating power.

Space does not permit a full description of the mode of occurrence of these geologic products, nor of the details of many other similar subjects that come close to man, but well can it be said that while the man of primitive ages developed only slowly in great periods of time, yet through the utilization of metals and other geologic products and geologic conditions, mankind in a vastly shorter time changed from a savage living solely by the hunt to the civilization of ancient historic times, and thence to that of the present day. In the Stone Age his efforts were engrossed in a struggle for existence against the elements and the wild beasts that surrounded him; today, with his actual existence assured against these dangers, his efforts are devoted to constructive endeavors and to defending himself not against the beasts of the forest, but against the ferocious attacks of the hostile elements of his fellow man.

Cultural Value of Geology

A knowledge of at least the general principles of geology is an important part of any liberal education and is essential in many scientific, literary, artistic, engineering and other pursuits of the present day. Nevertheless geology was the last of the great fields of research in natural history to receive scientific attention. Biology was well developed before the basis of geology on which it was founded received recognition. This was doubtless due to the fact that animal and plant life were more immediately noticeable to the casual observer than the nature of the rocks below, and thus scientific study began on the surface objects which attracted most attention; but as the spirit for research increased it tended to seek deeper and deeper below purely superficial manifestations, and thus revealed geology. Until the beginning of the last century the science of geology in its modern interpretation was hardly recognized as more than the vague conception of a few dreamers; today it demands the attention of the world as the basis of all human knowledge of natural history.

Those who have a knowledge of geology have a vast educational advantage over those who have none, for to them every continent, ocean, river, mountain, valley and even every creek, field or sand bank, has a meaning, which greatly increases their interest in the observation of nature. To the man who has no geologic knowledge continents and oceans mean only land and water, valleys and mountains mean only hol-

lows or elevated spots on the ground, and the various minor details of the earth's surface are looked on indifferently as things that occur as a matter of course, and may be convenient or objectionable, according to his line of thought.

The geologist interprets his science in a form that makes clear the dependence upon the earth of man and his best attainments in civilization, and he realizes the fact that the problems of human life and living are bound up with the problems of geology. Geologic history and the great records of evolutionary processes which it embodies not only in physical and biological aspects, but in psychological, social and economic lines, carries a wealth of instruction unequaled in any other field of learning. As geology becomes rounded out to a still greater fulness it will teach the world profound lessons in the evolution of the highest products of life and thus will have surpassing value in the education of mankind.

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ENVIRONMENT IN SEDIMENTATION AND STRATIGRAPHY[1]

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(Read before the Paleontological Society December 31, 1930)

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INTRODUCTION

It has long been known that adaptation is the key to the distribution of organisms; they are the resultants of the long sequence of environmental factors to which they and their ancestors have been exposed. That fact is and has long been well known. That it has received little attention from stratigraphers is patent from the reading of most works on stratigraphy published prior to about 1910 and many papers of much later date tell the same story, and, as stated by Milner, "Stratigraphers are apt to neglect the significance of the environment for the cult of the organism and the intimate detail of succession."

Sediments are produced, transported, and deposited as consequences or resultants of the environmental factors prevailing at the places of production, through the regions of transportation, and at the places of deposition, and after deposition they become a factor of major importance in controlling the distribution of the organisms of the bottom, which organisms on death become sedimentary materials.

Organisms have different degrees of sensitivity to environmental factors. Some, as the common dandelion, are little sensitive and may be found in varying degrees of abundance over extremely wide areas with

[1] Manuscript received by the Secretary of the Society January 23, 1931.

considerable range of environmental conditions. The shephards-purse is a somewhat similar plant. On the other hand, most plants are extremely sensitive, as exemplified by many rhododendrons, which endure cold with difficulty and will not thrive in soil in which much lime is present. Some plants are adapted to sand barrens, others thrive on such organic regolith as the peats, and still others are so strongly calciphyllic that they die if the soil does not contain lime. The plants living in the various environments in their turn become environmental factors and furnish homes, food, and protection for other plants and animals and these latter in their turn become environmental factors for still other animals and plants, the entire sequence not being present if its first factor is wanting.

Some animals, as the domestic cat and dog, can thrive over most parts of the world and make their lives in the face of almost any competition, whereas the penguin and the seal would be likely to have a difficult struggle in inland lakes and rivers. Most sedentary animals are intimately related to the bottom or substratum on which they dwell and are also closely adapted to a wide range of other environmental factors.

Some organisms may be essentially independent of one or more factors of an environment, but extremely sensitive to others. Thus, the cotton boll-weevil pays not a great deal of attention to temperature and rainfall, but does depend for its existence and perpetuation on the presence of the cotton plant as the essential environmental factor, but this factor of the environment can not escape the influence of temperature and rainfall and thus these indirectly affect the cotton boll-weevil. The lady bug which feeds on the white fluted cottony scale of the California citrus trees disappears when the scale is not present. The scale depends for its existence on certain trees, and these in their turn depend on the soil, the rainfall, the temperature and, no doubt, many other factors. The problems are extremely complex and it is doubtful if any large part of them is understood for any single environment. The results are extremely important for stratigraphy, as organisms appear and disappear in the rocks of the geologic column without, as yet, adequate explanation as to what were the causative factors for such appearance and disappearance, reference to movements of sealevel whereby depths of water and positions of the strand-line were changed being the ordinary explanations.

Sediments and organisms are more or less interwoven in their relations to each other, and sediments, like organisms, show different degrees of

sensitivity to environments with probably the higher degree residing in the sediments, as all sediments seem to be closely related to environmental conditions and there are none which are so independent of the environment as the common dandelion or the domestic dog. Some sediments, as the sands, may have the appearance of being only slightly sensitive, but when these are critically studied it is readily seen that all sands have their detailed characteristics determined by rather narrow ranges of the environmental factors. So far as the writer is aware there are no inorganic sediments which possess such cosmopolitanism as some animals and plants. Most sediments of inorganic character seem to owe their origin to a rather narrow range of environmental factors. Thus glauconite, for example, seems to require a rather nice relation of organic matter to other sediments deposited. Other unknown factors probably are concerned, but it seems that under conditions of small organic matter, iron remains in, or changes to, the oxidized form, when organic matter is large, the iron changes to the carbonate or sulphides, but under some intermediate condition glauconite forms. The iron sulphides occur in sediments in the three forms of marcasite, pyrite, and melnikovite. Acid waters lead to the formation of marcasite, slightly acid or neutral waters precipitate pyrite, and alkaline waters result in the deposition of melnikovite.[2]

It would seem unnecessary to state that the environmental conditions in any large body of water would be of wide range with corresponding ranges in the variety of sediments deposited and organisms dwelling on the bottom. This is the case now and it is most reasonable to assume that such was the case in every large body of water of past geologic periods. The statement has wider application in that every site of deposition possesses a range of environmental conditions and deposits sediments and supports a flora and fauna now, and possessed the same during past geologic periods in variety commensurate with the environmental range, and Dana must have been correct in the general application of his statement that "many a sandstone in New York and Pennsylvania is of contemporaneous origin with a limestone in the Ohio and Mississippi valleys,"[3] and it is thought that this can be proved in several examples from other regions. Thus limestones in all the varieties indicate environments commensurate with the varieties, the great range of sand-

[2] W. A. Tarr: Alternating deposition of pyrite, marcasite, and possibly melnikovite. Am. Min., vol. 12, 1927, pp. 417-421. Allen, Crenshaw, and Johnson: The mineral sulphides of iron. Am. Jour. Sci., vol. 33, 1912, pp. 169-236.

[3] J. D. Dana: Manual of geology, 1895, p. 398.

stones proves environments within the range responsible for the deposition of particles of sand dimension, the various conglomerates are evidence of a range of environments coordinate with the varieties, and the different shales indicate different environments for each variety, a black shale showing one condition, a red shale another. The most reasonable explanation of the various black shales of the Appalachian region is not that they were deposited in basins absolutely separated from the waters in which sediments of other character were deposited, but within the same basins under different environmental conditions, the faunas of each environment being those adapted to the conditions.

Environmental Forms and Distribution of marine Organisms

The organisms of the water are in the three environmental forms of plankton, nekton, and benthos. The first is more or less independent of the environment of the bottom, currents controlling its migrations or travels, and temperature, chemical and physical character of the waters, food supply, etcetera, determining persistence in the range of waters of the transporting currents. Nekton, likewise, are more or less independent of bottom conditions, various forms thriving equally over mud, sand and rocky bottoms so long as other controlling factors are not prohibitive. However, many, and perhaps most nekton, have some relation to the bottom environment in that the organisms of the bottom furnish in part the direct or indirect food supply and thus their occurrences would be in largest numbers over those bottoms which produced food in greatest abundance.

It is possible that most marine nekton and plankton if introduced into fresh waters would be troubled and probably die. This might occur in delta bays and lakes, in the lagoons behind some barrier islands, in estuaries, and about the mouths of rivers following heavy rains as has been described off the coast of India and elsewhere. Fresh-water forms would experience similar difficulty if introduced into salt water. Muddy waters taking the place of clear would make it difficult for both nekton and plankton.

The benthos are narrowly limited by the nature of the bottom materials. Certain forms thrive best on mud bottoms, others on sand bottoms, and others must have rock and shell bottoms. Some dwell in greatest abundance where marine plant life thrives; others where such is rare. Additional environmental factors are depth of water, agitation, turbidity, temperature, and the presence of other organisms to fur-

nish food or protection. In turn, each form of benthos may, and most probably does, have influence in determining the presence of other benthos and also the presence of certain nekton and plankton. The most important and profound factor of the environment determining the character of the benthos seems to be the nature and physical properties of the bottom materials, but it must be fully understood that these in turn are due to such environmental factors as depth, temperature, light, water agitation, etcetera. According to Sumner [4] the physical texture of the bottom materials is "foremost among the conditions determining the distribution of the bottom-dwelling organisms," and Herdman's studies of the faunas and bottom deposits of the Irish Sea led to a similar generalization.[5] Kindle's work on the organisms of the Bay of Fundy is illustrative in this respect.[6] One station with a black mud bottom gave 10 species; 5 pelecypods and 5 gastropods. Five stations were in the intertidal zone and from these were collected 14 species of pelecypods and 12 species of gastropods; 2 stations with gravel or rocky and sandy bottom yielded 13 species of pelecypods and 9 species of gastropods, and 2 stations with sandy mud bottom gave 17 species of pelecypods and 13 species of gastropods. Only 3 species, all gastropods, of the total of 51 species, were found in all three environments. Nine species, 4 pelecypods and 5 gastropods, were collected from the black mud and the sandy mud bottoms. Only a single species was confined to the black mud bottom. None of those common to the two types of mud bottom was found in the intertidal zone or on the gravel bottoms. Fourteen species, 5 pelecypods and 9 gastropods, were common to the intertidal zone and the sandy mud bottom, and of these, 8 species also occurred on the gravel and rocky bottoms.

The conclusions to be drawn from these figures of distribution are those of Kindle: to the extent that the physical and chemical characteristics of the sediments are similar, so do the faunas living on them approach similarity, and the greater the differences in the physical and chemical composition of the bottom materials, similarly, there are equal differences in the faunas living on them.

In the above comparison only the living shells were considered, but when all forms represented by both living and dead shells were counted

[4] F. B. Sumner: An intensive study of the flora and fauna of a restricted area of sea bottom. Bull. U. S. Bureau of Fisheries, vol. 28, 1908.

[5] W. A. Herdman: The marine zoology of the Irish Sea. Rept. Brit. Assoc. Adv. Sci., 1894, pp. 318-334.

[6] E. M. Kindle: Bottom control of marine faunas as illustrated by dredging in the Bay of Fundy. Am. Jour. Sci., vol. 41, 1916, pp. 449-461.

the contrast became greater. The total fauna from the soft, black mud bottom consisted of 14 species, the rocky sandy bottom yielded 26 species. Three species were common, only 7 per cent of the total fauna. This comparison, as Kindle points out, indicates the fallacy of the contention of some paleontologists that current action integrates the bottom differences of preservable faunal remains and the fallacious conclusion that the fossil faunas of all environments become uniform from this cause. Integration would imply a competency to the bottom waters of such character that organic particles of all dimensions and densities were transported and deposited together. This, except locally, is an impossibility.

The work of Walther on the faunas of the Bay of Naples has shown a more striking occurrence of the control exercised on the character of benthos by the nature of the bottom. Tauben Island and Bank rises from a muddy bottom ranging from 200 to 500 meters below sealevel, the top of the Bank extending from 45 meters below sealevel to 50 meters above sealevel. In 1885 the Bank was covered with calcareous sands on which lived a luxurious development of plant and animal life, and this existed in the midst of, but above, the relatively poor flora and fauna living on the muddy bottom. The mud environment and the calcareous sand environment, each with its characteristic fauna and flora, were only short horizontal distances from each other. On the calcareous sand environment there lived in 1885, 360 species of animals, on the mud bottom 142 species. Seventy species were common to the two environments. The relations were more strikingly different when only those animals with hard parts were counted, and as these are the only forms likely to be preserved in the geologic column it is necessary to make this comparison. The number of species living on the calcareous sand bottom which might become fossilized was 310 and on the mud bottom 45. The number of common species was 14. The two environments do not differ to a greater degree in their physical characteristics than they do in their faunas. A second study of these same portions of the sea-bottom, made by Walther in 1910, showed extremely great changes to have taken place in the environment of the calcareous sand bottom on top of the Bank. This bottom had locally become covered with lime-precipitating algæ, the earlier faunas had been largely expelled, and the earlier benthos was no longer present in its former distribution. This environmental and faunal change has taken place in the short interval of twenty-five years without there having been any

change in the position of sealevel beyond perhaps a slight building up of the bottom.[7]

Another striking example of the influence of environmental conditions, particularly agitation of the water and protection from waves, is that discovered by Vaughan among the corals of the Cocos-Keeling Islands of the West Indies. Vaughan found 23 species living in the lagoon back of the reefs, 20 species in the barrier pools and on the barrier flat, and 16 species on the exposed barrier. Of the 23 species of the lagoon only 3 were found to occur on the exposed barrier and one of these was so modified by the conditions that its identification with one of the species of the lagoon was difficult and might be impossible if only the stony skeleton was present.[8]

Similar control over the benthonic faunas by bottom materials are known from the geologic column. The Becsie formation of Anticosti Island in its southern exposures shows by its calcareous character that the bottoms were largely free from mud and that the conditions were such as make limy materials the dominating sediments. The rocks are characterized by a superabundance of *Virgiana barrandei* and *Phænopora superba*. In the exposures on the north side of Anticosti the contemporaneous deposits are far more argillaceous and as a consequence of this, or perhaps some other factors, *V. barrandei* is so rare as to be hardly present and *P. superba* has not been found at all in the shaly beds. These shaly beds, however, contain *Camarotoechia glacialis* and *C. fringilla* in great abundance, but these species are extremely rare and small in the limy beds on the south side. There is no question respecting the equivalency of the beds concerned. The calcareous rocks contain pebbles and some gravels on many levels, both on the north and the south shores, showing that waves and currents affected the bottoms, but it is obvious that these did little or nothing in the way of integrating the shells of the bottom animals. The Ellis Bay formation of the south side of Anticosti contains an abundance of *Parastrophia reversa, Dinorthis anticostiana, Clitambonites diversus,* and *Orthis laurentina,* whereas in the equivalent strata on the north shore of the island these species are rare or wanting. On the south side of the island the containing rocks are calcareous for *P. reversa* and *O. laurentina,* and shaly for *C. diversus* and *D. anticostiana.* On the north side the contemporaneous beds have a different lithology with much sand. The faunal differences on the

[7] J. Walther: Die Sedimente der Taubenbank im Golfe von Neapal. Abhandl. d. k. Preus Akad. Wiss., Berlin, Phys.-Math. Cl., 1910, pp. 1-49.

[8] T. W. Vaughan: Smithsonian Rept. for 1917, 1919, pp. 195-196.

two sides of the island are so great for these two succeeding formations that for a while in the early study of the Anticosti Island faunas the favorite hypothesis of a land barrier between the waters which made the deposits on the two sides of the island was considered. Almost equally as sharp differences exist on the two sides of the island in the faunas of the Vauréal formation. These faunal differences arise from the fact that the north shore rocks of Anticosti represent the shallower or shoreward portions of the neritic environment and the rocks of the southern exposures the deeper water phases. Bittner [9] has called attention to similar variation in sediments accompanied by equally as great variations in faunas in a section extending from the Bohemian Massiv of the East Alpine central zone in which section he defines four belts of sedimentary materials all of the same age and equivalent to each other, each belt being characterized by somewhat different faunal content. Kiaer [10] has described similar variations in the Norwegian Silurian, McLearn has seen the same in the Arisaig Silurian of Canada, and a splendid case is that of the Permian basin of west Texas where one phase of the deposits consists of great limestones of which much seems to be of algal origin and the other of red beds and gypsum without much in the way of organic matter. The writer suspects that examples will become more numerous as soon as application is given by stratigraphers to the principle that environment was as important a factor in organic control in the past as it is at present, and there is discarded the theory that wave action will generally distribute organic matter so as to make faunas of a sea-bottom everywhere similar.

It should always be remembered that each change in sediment, either laterally or vertically, creates a new environment, and if modern marine biologists are correct, these changes should be accompanied by similar changes in fauna and probably also flora. The latter change in turn has repercussions on the fauna. Changes in sediments are more likely and more common in the shallow epicontinental seas as those of the Paleozoic and other eras. This is the case in the vertical sequence of beds and in harmony with the principle of Walther such denoted similar variations in the lateral sense.

Up to very recent time geological philosophy has been so permeated with the theory that changes and differences of faunas are fundamentally

[9] A. Bittner: Aus dem Ennstaler Kalkhochgebirge. Verhandl. Geol. Reichanstalt, 1886, pp. 92-101.

[10] J. Kiaer: Das Obersilur im Kristianagebiete. Videnskabs-Selskabets Skrifter, i, Math.-Naturv.-Klasse, 1906, bd. ii, pp. 6.

due to advances and retreats of the sea, or to separating land barriers, that little or no attention has been given to the possibility that these faunal differences and changes may have been due to differences or changes in the faunal environment. The writer is of the opinion that the many movements of the land and sea and the many barriers which have been postulated to explain the differences in faunal content of the rocks of such shallow water areas as must have existed in the Appalachian Geosyncline, about and over the Cincinnati Arch, and similar ancient land bodies will ultimately in considerable degree yield to explanations referring the faunal differences to variations in environmental factors, particularly variations in the character of bottom materials which, as already pointed out, are the resultant of a large number of other environmental factors. He is also of the opinion that many of the postulated land barriers will ultimately be relegated to the limbo of things forgotten. These traditional theories, like many of their predecessors, will have served their purposes.

Changes of Benthos and Changes in Environment

As already pointed out, the bottom materials of the Tauben Bank underwent a strong change in the twenty-five years between 1885 and 1910 and this bottom change was accompanied by great changes in constitution of the fauna. What factor was responsible for the spreading of the lime secreting algæ is probably not known, but something was responsible even though it has not been determined. This difficulty of determining causative factors in the present environment shows the difficulty of their determination in past environments. In the Anticosti Ordovician the genus *Beatricia* is characteristic of a zone in the Vauréal formation. It then disappears and does not occur through several hundred feet of sediments. Why did it disappear? Evidently some environmental factors entered, or departed, and drove it from the bottoms of its previous occupancy. What these present or missing factors were has not been determined and it is possible they can not be determined. Where did the genus live in the meantime, as live it must have? The place or places have not been found. Some day they may be, and it is possible that the strata representing the bottom or bottoms of survival may be correlated with one of the zones of the Anticosti succession in which its remains occur, which, probably will be determined by the associated species. Recurrence of faunas, which also means recurrence of environment, was a favorite idea with the late Henry Shaler Williams,

but not a great deal has been done with it since his time. However, there are no reasons for not believing that it may have occurred many times.

Control of Distribution of Nekton and Plankton

The distribution of the nekton and plankton is independent to a considerable degree of the character of the bottom materials and hence their occurrence in sediments does not state a great deal with respect to the environment in which the containing sediments were deposited and the latter in their turn tell little of the environment in which the contained plankton and nekton lived. The planktonic graptolites in life probably were distributed in all waters not too cold, too salty, or too fresh, so far as it was possible for currents to carry them into such waters, and their remains would have settled to all bottoms into whose waters their living or dead bodies were carried, even to those bottoms whose overlying waters were too cold, too salty, or too fresh for the organisms to dwell therein. They could have been drifted into the fresh-water lagoons behind barrier islands, the lakes on delta plains, into fresh-water estuaries and anywhere else to which the tides, oceanic currents, or wind currents might have carried them. Thus it is idle to speak of "graptolite seas" until it has been definitely shown that the sediments which contain the graptolites in large numbers were actually deposited in the seas wherein the graptolites lived instead of being the sediments of waters into which the graptolites drifted after death or wherein they drifted alive and were killed because of the environment being unfit for their occupancy. It may have been the case that the planktonic graptolites did not live at all in the waters on the bottoms of which they entered the sediments in largest numbers, these sediments merely holding them because of being deposited under conditions favorable for preservation. Their general occurrence in occasional layers harmonizes with this view.

Similarly, such things as sharks teeth indicate little with respect to the environment of deposition of the sediments in which they are entombed. Living shelled protozoans of planktonic habit are distributed in all waters suitable for their dwelling and their occurrences in sediments have little value for determination of the environments in which the containing sediments were deposited as their dead shells may drift anywhere.

Environments of Life, Death, after Death, and Burial

In any consideration of the environments of organisms, four phases of the individual organic history must be considered. These are the environments in which the organisms lived, the environments in which they died, the environments in which the dead bodies and appendages endured after death, and the environments in which the preservable remains were entombed. These four environments of an individual's body and parts may be the same, as, for instance, the skeleton of a coral attached to the place whereon it grew; but on the other hand, the environment of entombment may be neither that of life, that of death, nor that of existence after death. These four environments need to be differentiated, and, as Wasmund notes, the paleobiologic and paleogeographic results: the reconstruction of the former life relationships, can only be attained when one appreciates and knows the relationships and environments of both life and death. To the collectivity of life relationships, the term of Biocoenose has been applied, and Wasmund [11] proposed the term of Thanatocoenose for the death associations and relationships. In life an organism is held to rather narrow environmental conditions by those factors which have organic control; after death it is as an inorganic sediment and is controlled by altogether different environmental factors, and the places of entombment of its preservable parts may bear no relationships to the life determining factors. In life the common sea urchin of the Gulf of Saint Lawrence, *Strongylocentrotus dröbachiensis*, requires certain marine associations. After death its shells are found in shallow and deep waters on bottoms where it never dwelt; on the marine marshes where it is carried by waves, tides and animals, again where it did not and could not dwell; and as food for crows, gulls, and probably other birds it is carried inland miles from the sea for possible entombment in peat beds and in the sediments of streams and lakes. Fish float for a long time after death and thus may enter waters in which they did not and could not have lived; the remains of fresh-water fishes probably thus enter marine deposits. The environment of entombment of the plantonic graptolites and trilobites in many instances was probably not that of life and it may not have been that of death. Death might have been brought about by their drifting into tidal fresh-water estuaries, or fresh- or brackish-water lagoons behind barrier beaches. Their burial in the estuaries or lagoonal sediments denotes

[11] E. Wasmund: Biocoenose and Thanatocoenose. Archiv. f. Hydrobiologie, Bd. 17, 1926, pp. 1-116.

nothing from the point of view of the homes of the planktonic graptolites and trilobites. Trilobite, graptolite and much other organic matter has low density and much surface for volume and hence could be readily carried by waters of low competency to environments quite different from those in which the possessing organisms lived or died. Thus in the Upper Mississippi Valley essentially all Cambrian strata carrying organic remains have them in the form of trilobite fragments and delicate brachiopods and at the same time these strata possess depositional features due to vigorous wave and current action, and it is possible that the environment of deposition, or entombment, may be entirely different from that of life and thus the former can not give a true picture of the life of that time in these seas. The Gulf of Kara Bughaz of the Caspian Sea has a current flowing into it from the latter, the current being of such competency as to build a delta. The waters of the Gulf are too salty to support much life, but numerous organisms float into it from the Caspian and die shortly after arrival, the numbers at times being said to be enormous. Their remains are probably being entombed in the deposits made in the Gulf where they may be found by some geologist of the future, who, if he assumed that the remains of these plankton and nekton are indicative of the life of the Gulf of Kara Bughaz, would most certainly reach erroneous conclusions both as to the life of these waters and the salinity of the waters that this life could endure. The remains of this life are being entombed not where the animals lived, but where they died. Shells of polar waters are certainly being carried to warmer latitudes by the icebergs originating where the animals lived and died, but the organisms are being entombed in environments which are different from either. On May, 1928, the strandline near Wilhelmshaven was covered wtih thousands of beetles, bugs, moths, etcetera. These lay on the strand in a band 20 to 50 centimeters wide near the line of the swash (spulsam). They seemed to have been drowned in the sea following an east wind and were washed from the sea to the strand. On the beach they were mingled with the remains of marine shells with the result that entombment of the latter and land insects became probable, the place of burial being neither the place of death nor the place of life for either the shells or the insects. Some of these insects may have been buried at sea, but this may not have occurred due to their floating until brought to the beach, until dissipation through decay, or to their being eaten by scavengers.[12]

[12] F. Trusheim: Massentod von Insecten. Natur u. Museum, Bd. 59, 1929, pp. 54-61.

Entombment of marine organisms in the sediments of terrestrial environments is brought about by the washing to the beach of the shells of protozoans and other small and light shells whence they may be carried inland by winds and buried in the sediments of environments which represent neither those of life nor those of death. The celebrated protozoan sands of Dog Bay on the Galway coast of Ireland and the shells in the Bermuda dune limestones are cases which are well known. It has lately been shown that the seacoast dunes of some parts of Hawaii contain 29 species of marine invertebrates and the shells of 4 land snails.[13]

Environment in preserving organic Matter until Entombment

Whether organic matter is preserved until entombment depends on the environmental conditions. There are many environments teeming with life, but the conditions are such that little or nothing is buried and hence this life leaves no record of its presence. This fact has long been recognized by the vertebrate paleontologist, but does not seem to have received a great deal of consideration from those who worship at the shrine of the invertebrates.

Land organisms do not have much chance to become buried in materials favoring preservation and thus their remains ordinarily are not common. This is realized by everyone. Thus the organisms of the uplands, the dry prairies, and the deserts of past geologic periods are not well known, but everyone appreciates that these environments were probably populated in numbers commensurate with the food supply at all times when the lowlands were populated. Conditions are vastly better in swamps and lakes, but generally poor in rivers, although there seem to be several cases of remarkable preservation in river deposits.

As noted above, many black shales, themselves a product of environmental conditions, are characterized by the abundant horizontal occurrence of planktonic graptolites, but this abundance is probably not a consequence of their having been more numerous in these waters than elsewhere, but because the bottom waters and bottom deposits which resulted in the black shales contained an abundance of hydrogen sulphide and this, with the physical character of the bottom, eliminated the scavenger organisms whose absence permitted the graptolites and other delicate organic remains to escape destruction until buried beyond possibility of molestation. Graptolites probably lived and died in waters over other marine bottoms in as equal and possibly greater abundance as over the

[13] N. E. A. Hinds: Bull. Bishop Museum, 1930, p. 72.

black mud bottoms, but on settling to the bottom from these other waters they descended into the capacious maws of the numerous organisms which feed on organic matter. The results are as we find them: remains of delicate organisms are not found in as excellent preservation in deposits made on bottoms which were favorable to scavengers as they are on those bottoms whose sediments indicate conditions unfavorable to the latter. Bottoms having conditions favorable to a large population of those organisms which feed on organic remains would not be likely to permit such to endure for a very long time.

Some organisms of fresh-water lakes serve a like function, thus a small, carp-infested lake in southern Wisconsin had every green plant destroyed by the fish, not a weed being left, and the muddy bottom was covered with small depressions about a quarter of an inch deep, made by the carp as they "mouthed" the mud to obtain therefrom anything which might serve as food.[14]

Beneath the waters of the Gulf Stream off the coast of New England, Verrill[15] reports the occurrence of great quantities of entire and broken shells. The waters are too deep for the shell breaking to be referred to wave and current action and Verrill states that "many fishes, like the cod, haddock, hake, etcetera, have the habit of swallowing shells entire, and after digesting the contents, they disgorge the uninjured shells, and such fishes abound there. The broken shells have probably been preyed on by the crabs and other crustacea having claws strong enough to crack the shells. The large species of *Cancer* and *Geryon,* and the larger paguroids, abundant in this region, have strength sufficient to break most of the bivalve shells. Although I have often seen such crustacea break open bivalves for food, I am well aware that they also feed on other things. Many fishes that feed on Mollusca can break the shells before swallowing them so that both fishes and crabs have doubtless helped to accumulate the broken shells that are very often scattered abundantly over the bottom, both in deep and shallow water. Such accumulations would soon become far more extensive if they were not attacked by boring sponges and annelids. Certain common sponges belonging to the genus *Cliona* very rapidly perforate the hardest shells, in every direction, making irregular galleries, and finally ultimately destroying them. In our shallower waters the most destructive species is *C. sulphurea* (Desor), which burrows in shells and limestone when

[14] A. R. Cahn: Carp in ponds. Science Service. Science, vol. 70, 1929, p. x.
[15] A. E. Verrill: Am. Jour. Sci., vol. 24. 1882, pp. 449-450.

young, but later grows into large, rounded, sulphur-yellow masses often a foot in diameter. Other species occur. Rarely, we dredge up, on the outer grounds, fragments of wood, but these are generally perforated by the borings of bivalves (usually *Xylophaga dorsalis*) and other creatures, and are evidently thus soon destroyed. Very rarely do we meet with the bones of vertebrates at a distance from the coast. Although these waters swarm with vast schools of fishes, while sharks, and a large sea porpoise, or dolphin (*Delphinus,* sp.) occur in large numbers, we have very rarely indeed dredged up any of their bones, or, in fact, remains of any other vertebrate animals. In a few instances we have dredged a single example of a shark's tooth and occasionally the hard otoliths of fishes. It is certain that not merely the flesh, but most of the bones, also, of all vertebrates that die in the region are very speedily devoured by the various animals of the bottom. Echini are very fond of fishbones, which they rapidly consume." Murray and Lee [16] state that in the South Pacific Ocean "Very many crustacea frequent this area to pick up the little particles of organic matter which are just settling to the bottom and some of them—like *Nyctiphanes*—are provided with phosphorescent organs to enable them to do this more effectively." "Large numbers of Holothurians and other marine creatures here eat the mud to obtain the organic matter associated with it; indeed it is more than probable that all marine deposits are in this way passed through the intestines of organisms." It should thus be obvious that on bottoms where scavengers are prevalent, delicate remains of organisms would have little chance of preservation.

The entire problem of the disposition of organic matter in terms of the environment after death and before entombment is summed up by Buchanon in his statement that "The same causes are at work in deep as well as in shallow seas," and "the matter forming the bottom of the sea is continually passed and repassed through the bodies of the numerous tribes of animals which demonstrably live on the mud and its contents." He also states that "the principal agent in the comminution of the mineral matter found at the bottom of the deep and shallow seas and oceans is the ground fauna of the sea, which depends for its subsistence on the organic matter which it can extract from the mud." [17]

It seems probable that in such environments, under slow conditions of

[16] J. Murray and G. V. Lee: The depth and marine deposits of the South Pacific Ocean. Mem. 38, Mus. Comp. Zool., 1909, pp. 160-161.

[17] J. Y. Buchanon: On the occurrence of sulphur in marine muds and nodules and its bearing on the mode of formation. Proc. Roy. Soc. Edinburgh, vol. 18, 1890-91, p. 20.

entombment, there would be little left to record the presence of the numerous organisms which had dwelt on the bottom and in the waters above. The only evidence of their presence would be comminuted shells which would not in all cases be likely to persist because of easy recrystallization due to the fine condition. There are many marine limestones which to the eye carry little or no organic matter but thin sections show many of these to be filled with such in various degrees of minute fragmentation with the containing rocks showing nothing to suggest wave action to a degree commensurate with the fragmentation. The fragmentation, which obviously is physical, must be referred to the work of scavenger organisms. Evidently these rocks accumulated in an environment favorable for the life activities of the organisms but at the same time one inimical to their preservation until entombment.

Entombment is determined by rate of accumulation of the entombing sediments and if these are being slowly deposited there is little chance of the organic material being preserved unless the conditions are like those of the waters in which the black shales were deposited, thus preventing the bottom-eating organisms from entering. It was the conclusion of Wepfer [18] that absence of fossils in sediments in many cases was a consequence of too slow, or cessation of, deposition of inorganic sediments and their abundance is the converse, that is, deposition was sufficiently rapid to bury the organisms as rapidly as they died, but not so fast as to make the conditions unfavorable for their existence. This condition in the environment makes preservation of organic material dependent in part on the environmental conditions on the neighboring lands.

Many marine limestones overlain by shales contain excellently preserved fossil shells on their upper surfaces, a preservation readily explained on the basis that the overlying shales were deposited sufficiently rapidly to bring about entombment before the shells had been seriously injured by scavenger organisms.

Sediments which bury organic materials should be deposited sufficiently rapidly so as to place the latter beyond the reach of the organisms that burrow through the mud in every direction eating the whole for the food that may be present. Only under conditions of rapid burial is there a certainty of preservation.

[18] E. Wepfer: Ein wichtiger Grund für die Lückenhaftikeit der paleontologischen Ueberlieferung. Centralbl. für Min., u. a., 1916, pp. 105-113. Terristrische Einflüsse bei der marinen Sedimentation und ihre Bedeutung. Zeitschrift der Deutschen geologischen Gesellschaft, Monatsberichte, Bd. 74, no. 1, 1922, pp. 39-47.

Slow deposition under ordinary conditions in shallow, oxygenated waters gives a most favorable environment for organisms, but one at the same time extremely favorable for scavengers with resultant elimination and disappearance of organic matter. Too rapid deposition renders a bottom inhospitable for organisms, but favorable for their entombment and preservation. Evidently some intermediate condition, with a rate of deposition neither prohibitive to organisms nor very hospitable to them, gives most possibility for their dwelling on the bottom and for their subsequent preservation and permanent entombment. Thus bottoms of low deposition under favorable conditions would be densely populated, but leave little record. Bottoms of rapid deposition would have a small benthonic population and poor faunal record would result. Excellent preservation of benthonic organic material thus implies a rather delicately balanced situation which probably was the exception and not the rule. Instability of environment as illustrated by a sequence of thin shales and limestones seems to give excellent conditions for the preservation of organic remains. The fact that the best preserved and least broken fossils are found in shales illustrates the principle here explained.

Summary

(1) Many of the facts and principles presented are elementary and apparently unnecessary of statement, but the rather general neglect of the influence of the environment in stratigraphic philosophy and literature warrants their presentation.

(2) The sediments are responses to environmental conditions operating on characters inherited from parent rocks and previous processes and deposition of all varieties is due to environmental factors operating at the places of deposition. Inorganic sediments have high degrees of sensitivity to environmental factors.

(3) Ancient seas had ranges of environment not unlike those existing in modern seas. Each environment of ancient seas was characterized by a sedimentary deposit if such was possible and a fauna and flora adapted to the conditions.

(4) The nature of the bottom, that is, the surface of the sediments already deposited, is a most important factor in the environment for the benthos, and this with the character of the bottom in turn influence the character of the nekton and plankton.

(5) After death organic matter becomes subject to the factors controlling inorganic sediments.

(6) Environments of organisms should be differentiated into those controlling the living organisms and those controlling the persistence and distribution of their dead bodies.

(7) Abundant preservation of nektonic and planktonic matter does not prove that the overlying waters were densely populated with such as these waters may have been the places of death and not of life.

(8) Absence of an abundance of organic remains in a formation does not prove a scarcity of life on the bottom of the formation's accumulation as the organic matter may have been destroyed by scavengers.

(9) An abundance of fossil benthonic organisms implies either a nicely balanced situation with sufficient sedimentary materials accumulating to produce entombment and not an excess prohibitive to habitation by many benthos, or an unstable environment of occasional slow followed by rapid deposition.

(10) Correlation on noncorrelation of strata with the factor of environment for both sediments and organisms, given little or no consideration, contains the probability of much error, and correlation on the basis of fossils alone is not entitled to a great deal of respect.

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CLASSIFICATION AND DURATION OF THE PLEISTOCENE PERIOD[1]

VICE-PRESIDENTIAL ADDRESS BY GEORGE F. KAY

(Read before Section E of the American Association for the Advancement of Science January 1, 1931)

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INTRODUCTION

"With the rapid progress of detailed geologic investigation throughout the world and the shift in viewpoint as one phase or another of the complex subject is emphasized, changes in classification must necessarily be made as rapidly as enough evidence is presented to convince the majority of geologists that they are desirable."—Stanton.

[1] Manuscript received by the Secretary of the Society January 7, 1931.

"But while we can not now, and probably may never, hope to divide geologic time into centuries and milleniums, we can divide it into periods, each of which has its own special significance in the history of the earth."—Grabau.

This paper has as its subject "Classification and Duration of the Pleistocene Period." Its chief purpose is to trace briefly the history of development of the present classification of the Pleistocene, to suggest a revision of this classification, and to present an estimate of the duration of each of the glacial and interglacial ages of the Pleistocene, and of the period as a whole.

The name Pleistocene was used originally by Lyell in 1839 for rocks which previously he had designated Newer Pliocene. His Pleistocene deposits were older than beds which he recognized as Post-Pliocene in age. Later, in 1846, Forbes used the name Pleistocene for glacial deposits younger than the Pliocene and older than the Recent. This usage of Forbes was adopted by Lyell in 1873 and has continued to the present time. The Pleistocene includes then the deposits of the Great Ice Age and contemporaneous marine, fluviatile, lacustrine, and volcanic rocks. By some geologists [2] some preglacial deposits and some postglacial deposits older than the Recent deposits have been included in the Pleistocene. In this paper Pleistocene and Glacial will be used interchangeably and will be given the rank of a period of the Cenozoic Era.

The justification for giving the Pleistocene the rank of period is that this part of geologic time "has its own special significance in the history of the earth." It is recognized, however, that with respect to the time involved the Pleistocene Period ranks among the shortest of the periods into which the history of the earth has been divided.

The Pleistocene or Glacial Period will be divided into epochs and ages, and the Pleistocene or Glacial system into corresponding rock terms, series and stages. With our present detailed knowledge of the Pleistocene there seems to be ample reason for following, insofar as possible, the same practice in classifying Pleistocene deposits as is followed in the classification of older, marine sediments.

Although it might be considered proper to include the time since the retreat of the last ice-sheet as the early part of another interglacial age of the Pleistocene it has seemed best to designate, somewhat arbitrarily, this postglacial time as the Recent age, comparable in rank to an age in

[2] J. E. Eaton: Divisions and duration of the Pleistocene of southern California. Bull. Amer. Assoc., Petroleum Geologists, vol. 12, no. 2, February, 1928.

the Pleistocene Period. A common usage is to include the Pleistocene and Recent as epochs of the Quaternary Period.

All the available evidence at the present time would seem to indicate that the records of the Pleistocene glacial and interglacial ages have been preserved more satisfactorily for study and interpretation in the Mississippi Valley area than in any other known area of the earth. Nor have the Pleistocene deposits been studied anywhere more thoroughly or classified in greater detail than in this Mississippi Valley region. Moreover, it is generally conceded that of all the States in the Mississippi Valley, Iowa has the most available evidence from which to interpret the history of the Pleistocene, to classify the deposits which belong to this geological system, and to estimate the duration of the period.

As a result of field and laboratory studies in Iowa extending over many years the writer feels more competent to deal with this area than with any other. For this reason the chief facts and interpretations to be presented in this paper will be based on evidence gained by himself and many other students of glacial deposits within the borders of this State and of adjacent States. The problems of this limited field would seem to be the main problems of the continent so far as the Age of Ice is concerned.

History of Development of Pleistocene Classification

A fairly comprehensive history, accompanied by references, of the investigations and classifications of the Pleistocene of Iowa and adjacent States is available.[3] Hence, in the present paper consideration will be given only to such phases of the history as are essential to a proper understanding of the development of our present generally accepted classification of the Pleistocene. With such a background it will not be difficult to proceed to the consideration of the evidence which would seem to justify a revision of this classification and to a discussion of the factors which enable estimates to be made of the duration of the Pleistocene.

From the year 1837, when Louis Agassiz first put forward the view that there had been continental glaciation in Europe, until the present, glacial phenomena have been studied by many geologists, and year by year, as investigations have continued, more and more of the complex history of the deposits which were made during the Pleistocene or Glacial Period has been unraveled. At first it was believed that all the phenomena could be explained in relation to the advance and retreat of a single ice-sheet.

[3] G. F. Kay: History of investigations and classifications of the Pleistocene deposits of Iowa. Iowa Geol. Survey, vol. xxxiv, 1929, pp. 70-133.

But soon evidence was found which indicated that there had been two ice-sheets separated by a long interglacial age. This evidence consisted in many places of a forest bed or buried soil separating two tills. For instance, buried soils were described in Illinois as early as 1868 by Worthen. Even before this year similar evidence had been found in Europe. A few years later Chamberlin emphasized differences in topographic form and degree of alteration as bases for differentiating tills. In fact, he put greater emphasis on the significance of these features than on forest beds.

McGee did extensive field work on the Pleistocene deposits of Iowa, particularly of northeastern Iowa, between the years 1875 and 1895. Here he recognized two tills both of which were older than the drift which earlier had been differentiated by T. C. Chamberlin in Wisconsin as the Second Glacial Drift (the present Wisconsin drift). McGee named his two tills the Upper Till and the Lower Till, the basis of separation being a forest bed or its stratigraphic equivalent, "hardpan" or "gumbo." He pointed out that his Upper Till was younger than the gumbo-surfaced till (present Kansan till) of southern Iowa and older than the till of the Des Moines lobe in Iowa (present Wisconsin till). McGee did not differentiate within his northeastern Iowa area a third drift, the oldest of the region (the present Nebraskan drift).

While McGee had been studying the glacial deposits of Iowa, N. H. Winchell had been investigating Pleistocene deposits in Minnesota, and T. C. Chamberlin had been carrying forward glacial studies in Wisconsin and in many other States. Chamberlin, while he was State Geologist of Wisconsin, and later while Geologist in charge of the Glacial Division of the United States Geological Survey, had unusual opportunities to become familiar with glacial and interglacial deposits in many parts of the glaciated field. His counsel was sought whenever matters involving the Pleistocene of any place in America were under consideration. His constructive criticisms and his interpretations were based on his intimate and extensive knowledge of widely distributed glacial deposits and his keen insight into the problems involved in the unfolding of the history of Pleistocene deposits in all their aspects. Not only did he study how to solve the problems of glacial and interglacial deposits, but he was accorded leadership in classifying and naming the deposits.

In 1893 Chamberlin and McGee examined together the now famous exposures of tills and gravels in the Afton Junction-Thayer region in Union County, Iowa. Here are two tills separated in some places by weathered gravels and in a few places by peat beds. Chamberlin named

the upper till East Iowan and the lower till Kansan; and later he named the interglacial interval between the retreat of the Kansan ice-sheet and the invasion of the East Iowan ice-sheet the Aftonian interval. The gravels were interpreted to be fluvioglacial gravels related in age to the Kansan till. The East Iowan and Kansan tills of the Afton Junction-Thayer region were thought at this time to be of the same age as McGee's Upper Till and Lower Till, respectively, of northeastern Iowa. Later, the name East Iowan was changed to Iowan. The recognized classification of Pleistocene deposits at this time was as follows:

(a) In the Afton Junction region
Iowan till
Aftonian—peats, mucks, soil bands, etcetera
Kansan till and associated deposits

(b) In northeastern Iowa
Iowan till—Upper Till
Aftonian—McGee's forest bed, "hardpan" or "gumbo."
Kansan till—Lower Till.

For some time the Des Moines glacial lobe in Iowa had been known to be younger than the Iowan and to belong to the drift which in Wisconsin had been named Wisconsin by Chamberlin.

In 1895 Dawson used the name Albertan for a boulder clay in Alberta, Canada, which he interpreted to be older than the Lower Till (Kansan) of McGee's area of northeastern Iowa.

The present Iowa Geological Survey was organized in 1892, with Samuel Calvin as State Geologist, and the members of this Survey at once took an active interest in the glacial deposits of the State. As a result of their investigations and the investigations of other geologists the characteristics and relationships of the tills, gravels, forest beds, loesses, and associated materials of Pleistocene age in many parts of the State soon became better understood. It was found that between the Lower Till or Kansan till and Upper Till or Iowan till in northeastern Iowa there were widespread weathered gravels which were interpreted to be fluvioglacial in origin and to have been deposited during the retreat of the Kansan ice-sheet. The weathering of the gravels was thought to have taken place during the Aftonian interglacial interval. These gravels were given the name Buchanan by Calvin and were correlated at this time with the weathered gravels in the Afton Junction region, which had become known as Aftonian gravels. It was recognized that thev

were fluvioglacial gravels which had been weathered to their present condition during the Aftonian interglacial interval.

But soon there was sufficient evidence to justify the interpretation that the two tills being mapped in northeastern Iowa, the Upper Till or Iowan and the Lower Till or Kansan, were not of the same ages as the upper or Iowan till and the lower or Kansan till, respectively, at Afton Junction. Nor did the Buchanan gravels prove to be of the same age as the Aftonian gravels. It was found that the lower till in the Afton Junction-Thayer region had been deposited by an ice-sheet older than the one which deposited the Lower Till, the Kansan, of McGee's area, and that the Iowan till above the Aftonian gravels at Afton Junction was the till which had been mapped Lower Till or Kansan till in northeastern Iowa, first by McGee and later by members of the Iowa Geological Survey. The solving of these relationships resulted in the name Kansan being shifted from the lower till in the Afton Junction region to the upper till of that region, and the name Pre-Kansan or Sub-Aftonian being given to the older of the two tills there.

The classification of the Pleistocene deposits after the revision was as follows:

(a) In the Afton Junction region—
Kansan till
Aftonian gravels, peats, etcetera
Pre-Kansan, Sub-Aftonian or Albertan till

(It will be observed that the gravels here were at this time named Aftonian gravels, not because of their time of deposition, which was during the closing stages of the Pre-Kansan glacial age, but because the weathering of the gravels occurred during the Aftonian interglacial age.)

(b) In McGee's area of northeastern Iowa—
Iowan till or Upper Till
Buchanan gravels
Kansan till or Lower Till.

Here the gravels separating the tills were named Buchanan gravels, not in relation to their time of deposition, which was during the closing stages of the Kansan glacial age, but because they became weathered during the Buchanan interval.

Both the Aftonian gravels and the Buchanan gravels were interpreted

to be fluvioglacial in origin, the former being related in age to the Pre-Kansan age and the latter to the Kansan age. It should be kept clearly in mind that for some time after the revision in the classification of the Pleistocene deposits of Iowa no Pre-Kansan till or Aftonian deposits had been differentiated in northeastern Iowa.

After Chamberlin had seen the field evidence on which the shifting of names had been made he stated in an editorial in the *Journal of Geology*, volume IV, "It seems best to accept the application of the nomenclature of the Iowa Geological Survey. This places the Aftonian beds below the Kansan series instead of above them."

Up to the year 1896, only two tills had been differentiated and mapped in northeastern Iowa, namely, the Kansan (McGee's Lower Till) and the Iowan (McGee's Upper Till). But in the summer of 1896, for the first time, Pre-Kansan till underlying a distinct peat bed was exposed for study in a railroad cut on the Chicago Great Western Railway, southeast of Oelwein, in Fayette County. The section was interpreted by Calvin, Beyer, Chamberlin and others as one which showed three tills, namely, Pre-Kansan, Kansan, and Iowan, also interglacial deposits of the Aftonian and Buchanan horizons. The Aftonian here was a peat bed or forest bed.

This discovery of a section showing a distinct forest bed below the two tills which had been mapped Lower Till or Kansan and Upper Till or Iowan, rather than between these two tills, caused some confusion. McGee had emphasized the fact that a forest bed separated his Lower Till from his Upper Till. After three tills rather than two had been recognized in McGee's area of northeastern Iowa some geologists believed that the name Kansan should have been given to the lowest of the three tills, that the name Iowan should have been given to the intermediate till, and that a new name should have been given to the uppermost till of the region. But good arguments have been put forward by Calvin and others in defense of the usage which has been maintained by the Iowa Geological Survey and by geologists generally. Moreover, recent field studies in McGee's area have revealed evidence which shows clearly that the name Iowan has been, and is now, used for McGee's Upper Till, which till was the basis for the name Iowan being given to the Upper Till at Afton Junction, and that the name Kansan is being used for McGee's Lower Till if proper emphasis is given to his descriptions of his two tills rather than too great stress being given to his forest bed alone, as has been the tendency of some geologists. At the time the Oelwein cut was described, only gravels and sands separating the Kansan and the Iowan

tills had been found by Calvin and his associates, whereas McGee emphasized the number of well records in which a forest bed or "hardpan" or "gumbo" separated his Lower Till from his Upper Till. But it is now known that in McGee's area there is in some places vegetable material (a forest bed) and in many places gumbo (now called gumbotil) at the same stratigraphic horizon as the Buchanan sands and gravels, and that there is a forest bed and related materials at the stratigraphic horizon of the Aftonian. Quite naturally, therefore, McGee's forest bed in some of his sections is the forest bed between the Kansan till and the Iowan till as these names are now applied, and in other sections the forest bed lies between the Kansan till and the Pre-Kansan till (present Nebraskan till). It is probable that in some of McGee's well records the forest bed did correctly delimit his Upper Till. It is also undoubtedly true that in other records he included two tills above his forest bed. Furthermore, one is forced to the judgment, from present knowledge of the area, that his forest bed lay in places within a single till which elsewhere is now known to be either his Upper Till or his Lower Till. But independently of well records there is no doubt that there is in northeastern Iowa an upper widespread till-sheet resting on an older till which has its own distinctive features. The upper of these two tills has long been mapped areally as Iowan till and the lower as Kansan till.

Before the year 1897 Leverett had differentiated the Illinoian till in Illinois and southeastern Iowa. This till was interpreted to be younger than the Kansan till and older than the Iowan till. The generally accepted classification of the Pleistocene at this time (1897) was as follows:

Wisconsin
  Interglacial stage (Toronto ?)
Iowan
  Interglacial stage (unnamed)
Illinoian
  Buchanan
Kansan
  Aftonian
Pre-Kansan, Sub-Aftonian, Albertan

After the identification of the Illinoian till and the determination of its relationships to the Kansan and Iowan tills it was evident that the term Buchanan for an interglacial stage was open to criticism.

In 1898 Leverett introduced the names Yarmouth, Sangamon and

Peorian into the classification of Pleistocene deposits of the Mississippi Valley. The name Yarmouth was applied to the soil and weathered zone at the junction of the Illinoian and Kansan till-sheets; the name Sangamon to the soil horizon between the Illinoian till-sheet and the Iowan loess (present Peorian loess), which at that time was thought to be related to and of the same age as the Iowan till; and the name Peorian to the weathered zone at the contact of the Iowan loess and the Wisconsin till.

In 1899 Leverett, in his monograph on "The Illinois Glacial Lobe," presented the following classification of the Pleistocene deposits of the Mississippi Valley, from the oldest drift-sheet to the youngest: (1) Oldest recognized drift-sheet, Albertan of Dawson, and Sub-Aftonian of Chamberlin; (2) Aftonian interval; (3) Kansan drift; (4) Yarmouth interval; (5) Illinoian drift; (6) Sangamon interval; (7) Iowan drift and main loess deposit; (8) Peorian, possibly equivalent to Toronto of Chamberlin; (9) Early Wisconsin morainic drift; (10) unnamed interval shown by shifting of ice lobes; (11) Late Wisconsin morainic drift; (12) (13) (14) and (15) stages of Lake Chicago as given in an earlier publication.

The published record shows that this classification of 30 years ago had the approval of all glacial geologists who were familiar with the glacial and interglacial deposits of the Mississippi Valley. It differs but little from the classification of today. Both classifications include five glacial stages (including Wisconsin substages) and four interglacial stages. The names of the stages are the same in the two classifications except that now the name Nebraskan is used generally for the oldest glacial stage, and the main loess deposit, which was originally interpreted to be Iowan loess, has been called for many years Peorian loess. The name Nebraskan was introduced into the classification by Shimek in 1909 in connection with his studies in western Iowa and eastern Nebraska. The Jerseyan of New Jersey has been correlated with the Nebraskan of the Mississippi Valley.

From about the beginning of the present century until now the drift-sheets and interglacial deposits have been subjected to detailed study, the results of which have given clearer conceptions of the several epochs of the Glacial Period and of the period as a whole than were possible earlier. Former views have been modified and a better understanding has been reached with regard to many intricate problems, some of which have been explained satisfactorily whereas others still await solution. Two questions suggest themselves: Has there been developing in recent

years sufficient "shift in viewpoint as one phase or another of the complex subject is emphasized" to warrant consideration of a revision of the generally accepted classification? And, Does our present detailed knowledge of the origin and history of the glacial and interglacial deposits furnish a basis for a judgment as to the duration of the Pleistocene?

Significant Features of the Pleistocene

Relationships of Pleistocene Materials

Satisfactory answers to the questions just raised can be made only after the presentation of the general consensus of opinion among glacial geologists today with regard to the most significant features of the glacial and interglacial stages of the Pleistocene.

In figure 1 an attempt has been made by means of diagrammatic sections of glacial and interglacial materials to represent the present-day interpretations of the relationships of Pleistocene materials in Iowa, where, as stated previously, the records of the glacial and interglacial ages of the Glacial Period have been best preserved and where the deposits have been studied in such detail as to permit of their satisfactory interpretation and classification. A careful study of these sections will aid in making clear some of the statements which will be made regarding the characteristics and relationships of the materials to which consideration must be given in any attempt to establish a satisfactory classification of the Pleistocene.

Nebraskan Drift and Related Materials

In Iowa and border districts the first ice-sheet, the Nebraskan, came from the Keewatin center and covered a large area in the Mississippi Valley. The evidence suggests strongly that this oldest ice-sheet advanced over an area on which had been developed a topography characteristic of a mature erosional surface, with broad valleys, moderate slopes, and complete drainage systems. The drift left by this ice-sheet has been estimated to have had a thickness of more than 100 feet, possibly as much as 150 feet. The drift consists of boulder clay or till with associated sands and gravels. This Nebraskan drift is at the surface in restricted areas only (see figure 6), as it is overlain in many places by younger drifts. The evidence as revealed in Iowa and adjacent States indicates that when the Nebraskan ice withdrew there was left over large areas a comparatively flat, poorly drained ground moraine plain. Till was the material left most widely at the surface of this plain; in places on the plain were sands and gravels. During the Aftonian interglacial age this drift underwent important

FIGURE 1.—*Diagrammatic Sections of glacial and interglacial Materials in the Pleistocene of Iowa*

changes. The unoxidized and unleached Nebraskan till, where so situated that chemical weathering was effective and erosion was negligible, was changed stage by stage until Nebraskan gumbotil was developed to an average thickness of more than 8 feet. Where gravels were subjected to weathering throughout Aftonian time under topographic conditions similar to those under which gumbotil was developed from till these gravels underwent great chemical changes also, changes comparable to those which the till underwent in the formation of gumbotil. In fact, in places in Iowa upland Nebraskan gravels are known which during Aftonian time were thoroughly leached of their calcium carbonate to a depth of 20 feet. Lenses and irregular masses of gravels incorporated in the Nebraskan till are weathered but little. In places peat instead of gumbotil was formed on the Nebraskan ground moraine plain. After the development of gumbotil on the Nebraskan ground moraine plain much of the plain was eroded, leaving only remnants of the former widespread Nebraskan gumbotil plain, and in places within the eroded areas sands and gravels were deposited.

The record of the weathering of the Nebraskan drift is well preserved in many places in Iowa because the gumbotil and related materials were covered by the drift of the second ice-sheet, the Kansan. In the slopes of valleys, in road and railroad cuts, and in other excavations which go below the old Nebraskan surface, there are exposures of the Nebraskan gumbotil and underlying zones. In places the Nebraskan drift was all eroded before the coming of the Kansan ice-sheet, elsewhere the Kansan glacier removed only a part of the Nebraskan drift. Under such conditions the upper part of the Nebraskan drift is absent, and where the remaining Nebraskan drift is overlain by Kansan drift it is difficult to distinguish one drift from the other.

KANSAN DRIFT AND RELATED MATERIALS

The second drift-sheet, the Kansan, also covered a large area in the Mississippi Valley. This drift has been estimated from field evidence to have had an average thickness above the Nebraskan gumbotil plain of about 50 feet. When to this figure is added the material necessary to fill the valleys cut in the Nebraskan drift the Kansan is seen to be also a massive drift to be ranked with the Nebraskan as one of the great drift-sheets of the Pleistocene. During the Yarmouth interglacial age the Kansan drift underwent changes similar to those to which Nebraskan was subjected in Aftonian time. That is to say, on the flat, poorly drained, Kansan ground moraine plain there was developed a gumbotil with maxi-

mum thickness of about 15 feet and average thickness of more than 11 feet. Gravels of Kansan age, where they were subjected to weathering under conditions similar to those under which Kansan till was being changed to gumbotil, became strongly oxidized and leached. In places these upland Kansan gravels were leached to a depth of about 30 feet during Yarmouth interglacial time. As in the case of the Nebraskan, after the development of gumbotil and related weathered materials on the Kansan ground moraine plain this plain was considerably eroded, leaving only remnants of the former widespread Kansan gumbotil plain, the largest of which remnants are in southern Iowa and northern Missouri. In places within the eroded areas sands and gravels and, in places, loess were deposited before the deposition of the Illinoian drift.

In many places in Iowa and adjacent States the Nebraskan and Kansan drifts closely resemble each other. Only locally can the Nebraskan drift be differentiated lithologically from the Kansan drift. In fact, the only satisfactory basis found thus far on which to decide definitely whether a pre-Illinoian drift is Nebraskan or Kansan is the relationship of the drift to interglacial materials whose age can be determined. Among the most widespread of interglacial materials separating Nebraskan from Kansan till is gumbotil. If a till is overlain by Nebraskan gumbotil or can be shown to be related to Nebraskan gumbotil, which in Iowa is found as remnants of a former extensive Nebraskan gumbotil plain, the till is Nebraskan till. If, however, the till is overlain by a gumbotil which is known to be a remnant of the former extensive Kansan gumbotil plain the till is Kansan till. In fact, the gumbotils, on account of their distinctive characters, wide distribution, and topographic positions are the most satisfactory criteria that have been found for differentiating the older drifts. They have proved to be the most satisfactory Aftonian and Yarmouth horizon markers. They have been useful especially in differentiating and mapping the Nebraskan and Kansan drifts over wide areas. Figure 2 shows outcrops of Nebraskan gumbotil of Aftonian age separating Nebraskan till from Kansan till in Iowa, and figure 3 shows outcrops of Kansan gumbotil of Yarmouth age. From these outcrops it is possible to map areally the Nebraskan and Kansan drifts. Moreover, the Nebraskan gumbotil outcrops and the Kansan gumbotil outcrops mark the positions of the surfaces of the ground moraine plains on which the gumbotils were formed. From the altitudes of these outcrops it is possible also to construct maps to show the attitude of the Nebraskan and Kansan till surfaces during Aftonian and Yarmouth ages, respectively (see figures 4 and 5).

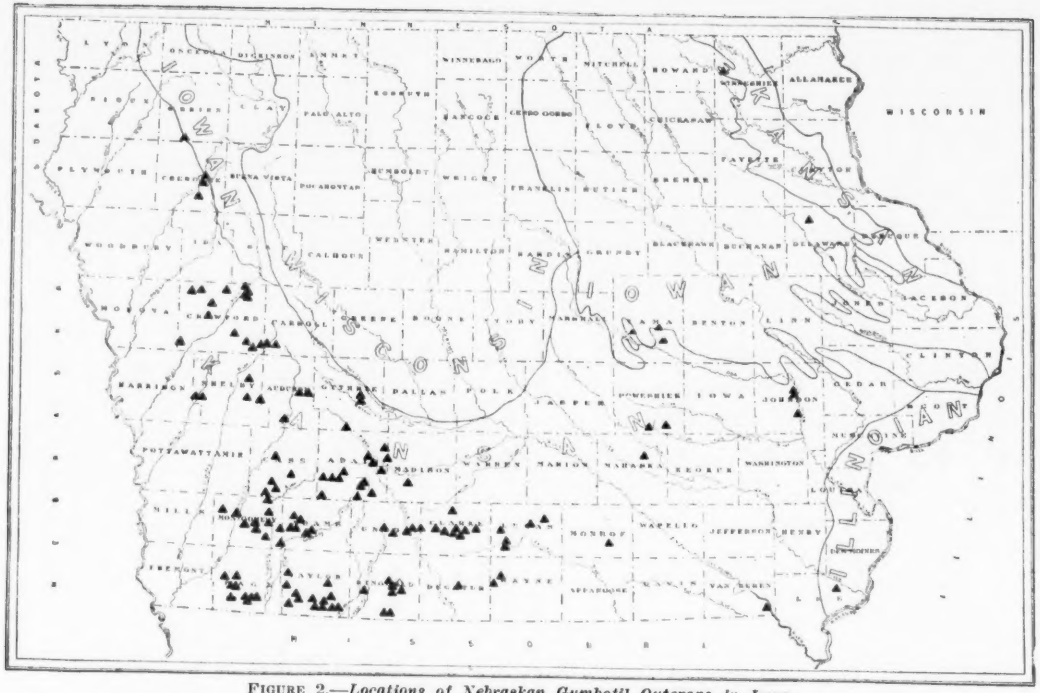

FIGURE 2.—*Locations of Nebraskan Gumbotil Outcrops in Iowa*
This gumbotil, indicated by triangles, is the chief Aftonian interglacial horizon marker in the State.

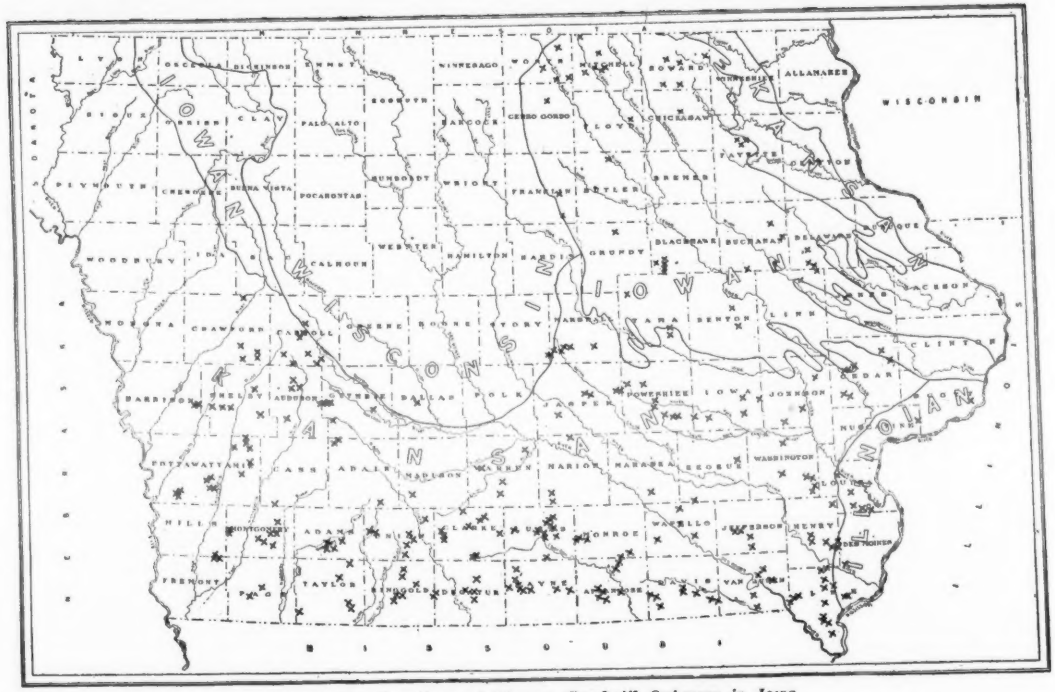

FIGURE 3.—*Locations of Kansan Gumbotil Outcrops in Iowa*

This gumbotil, indicated by crosses, is the chief Yarmouth interglacial horizon marker in the State.

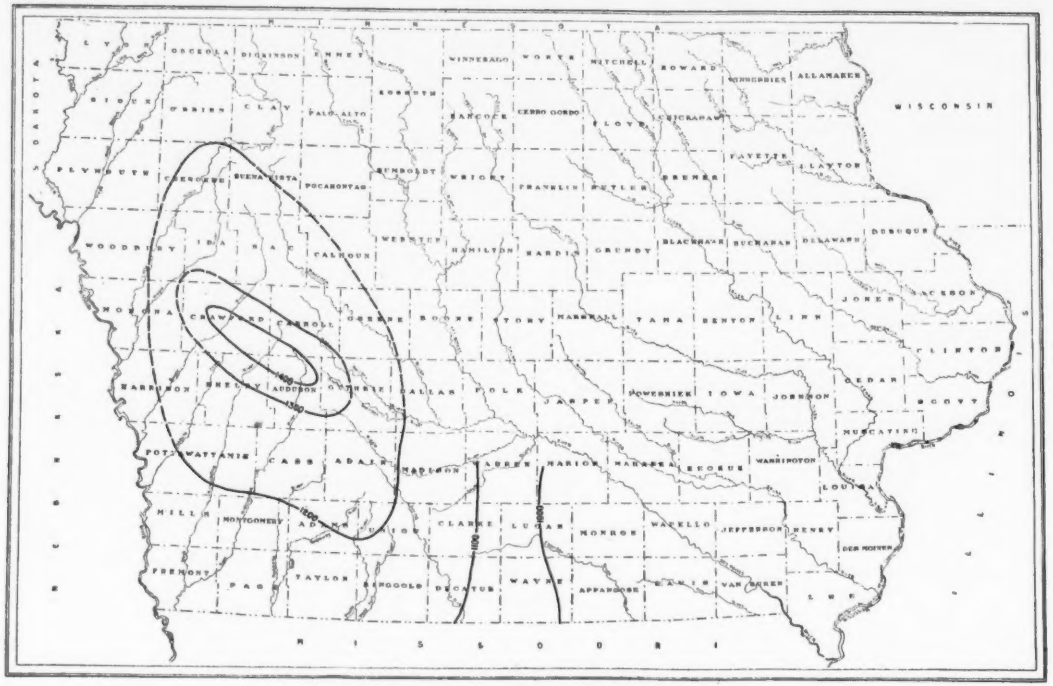

FIGURE 4.—*Contour Map of Nebraskan Plain*

Showing the surface of the Nebraskan plain in western Iowa on which gumbotil was formed during Aftonian time. Contour interval, 100 feet.

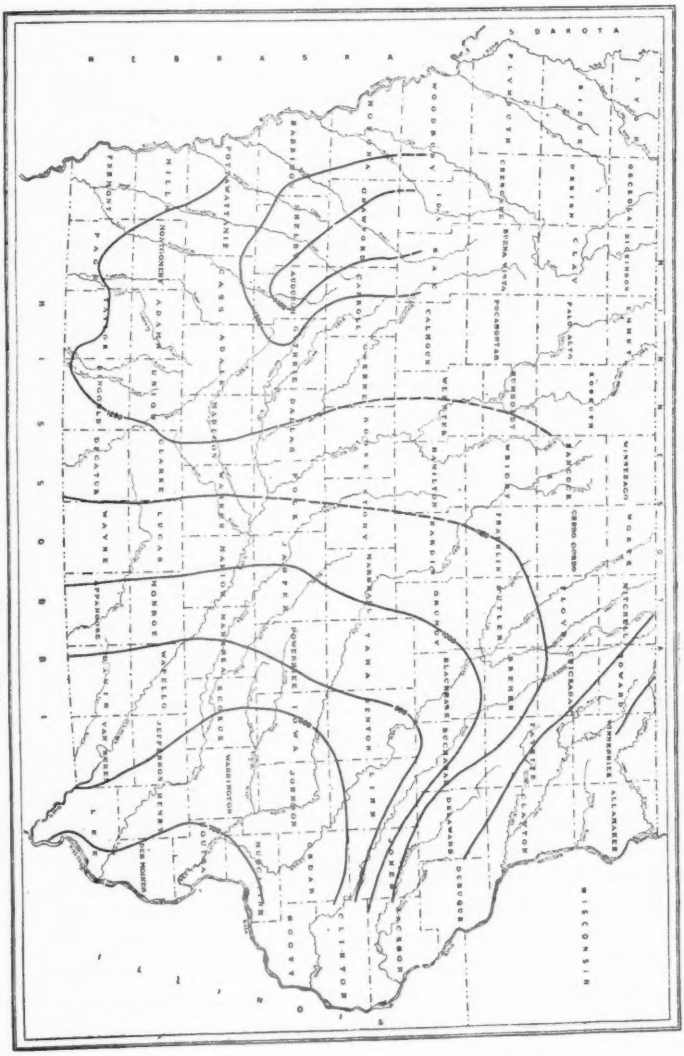

FIGURE 5.—*Contour Map of Kansan Plain*

Showing the surface of the Kansan plain on which gumbotil was formed during Yarmouth time. Contour interval, 100 feet.

Peats and weathered gravels have been and will continue to be of value in interpreting Aftonian and Yarmouth interglacial history, but they have been found to be less serviceable than the gumbotils in areal mapping. Only a few good peat exposures of Aftonian age have been found in the Mississippi Valley and these are widely separated from one another. Nor are there many known good exposures of peat of Yarmouth age. Moreover, since gravels differ in origin, in composition, in topographic position, in degree of weathering, and in other respects, their use in mapping is somewhat restricted. Much less reliance is now placed on interpretations of gravels and "forest beds" penetrated in well drillings than was given to these materials in the earlier years of Pleistocene studies. Loess of late Yarmouth age is present in places in Illinois and Iowa.

ILLINOIAN DRIFT AND RELATED MATERIALS

The third ice-sheet, the Illinoian, came into Iowa from the Labradorean center. The drift left by this ice-sheet is exposed widely in Illinois, Indiana, and Ohio. A lobe of the Illinoian ice extended into southeastern Iowa, displacing the Mississippi River from its present location westward to a position where it remained until post-Illinoian time. The Illinoian drift, which has an average thickness of about 30 feet, has the same general characters as the Nebraskan and Kansan drifts. Extensive areas of its surface are flat, and uneroded. In limited areas the topography is distinctly morainic. During the Sangamon interglacial age Illinoian till also was weathered to a gumbotil with a depth of 4 to 6 feet where the topographic conditions were similar to the topographic conditions under which gumbotil was developed on the Nebraskan and Kansan tills.

Within the Illinoian drift area there are in many places two loesses on the Illinoian gumbotil and on eroded surfaces of Illinoian drift. The younger of these two loesses is the Peorian loess; the older loess has been correlated by the writer with the widespread Loveland loess of western Iowa, which is later than the Kansan gumbotil erosion and is pre-Iowan in age. Leverett, however, correlates the Loveland loess of western Iowa with pre-Illinoian loess and questions the existence of a post-Illinoian, pre-Peorian loess. But in recent years this older loess on the Illinoian has been mapped widely by members of the Illinois and Iowa Geological Surveys. Although the Loveland loess of western, central, and southern Iowa outside the limits of the Illinoian area appears to be a single formation which was deposited in post-Illinoian, pre-Iowan time, the writer has stated that in reality its lower part may be pre-Illinoian in age, and

only its upper part post-Illinoian; and it may be that a part of the Loveland loess where it lies on drift older than the Illinoian was deposited during the Illinoian glacial age. The older of the two loesses on the Illinoian drift has been referred to late Sangamon time by the geologists of the Illinois Survey.

IOWAN DRIFT AND PEORIAN LOESS

The fourth drift-sheet is the Iowan, which in the Mississippi Valley is limited in distribution (see figure 6). Its characteristics are best known from studies in northeastern Iowa. The Iowan is thin, having an average thickness of less than 10 feet. Its topography is a drift-mantled, erosional type, although the mantle is in places thick enough to produce distinctly depositional features. In parts of the area the relief is very slight and the surface appears to the eye to be almost level. In Iowa the Iowan was deposited on Kansan gumbotil, on the eroded surfaces of the Kansan drift or on Loveland loess. Since the retreat of the Iowan there has not been sufficient time for the development of gumbotil. However, leaching of calcium carbonate has proceeded to a depth of somewhat more than 5 feet.

In recent years Leverett has contended that the Iowan is a Keewatin phase of the Illinoian. But Kay, Alden and Leighton, and other geologists have presented evidence to show that the Iowan is much more closely related in age to the Wisconsin than to the Illinoian. The writer has contended also that the Sangamon interval, which separates the Iowan and the Illinoian glacial ages, was much longer than the Peorian interval—long enough for gumbotil more than 3 feet thick to have been developed on the Illinoian till, also for post-Illinoian gumbotil erosion, also for the deposition of a loess on this eroded Illinoian and weathering of the loess before the close of Sangamon time.

The Peorian interglacial age was characterized by widespread loess deposition. This loess was apparently laid down shortly after the deposition of the Iowan drift and not long before the deposition of the Early Wisconsin drift. It varies in thickness from a few feet to a thickness of nearly 100 feet adjacent to wide floodplains. In places this loess is apparently genetically related to the Iowan. The writer[4] has shown in a recent paper that the depth of leaching of the Peorian loess in Iowa where it is not overlain by Wisconsin drift is about the same as the depth of leaching of the Iowan till which has been subjected to leaching since

[4] G. F. Kay: The relative ages of the Iowan and Wisconsin drift-sheets. Amer. Journ. of Science, vol. 21, February, 1931, pp. 158-172.

the retreat of the Iowan ice-sheet from Iowa. The presence of a pebble band on the Iowan drift beneath the Peorian loess is one of the arguments advanced by Leverett for the interpretation that the Peorian loess is much younger than the Iowan—the Iowan being considered by him to be comparable in age to the Illinoian.

WISCONSIN DRIFT

The youngest of the drifts is the Wisconsin. It is the most widespread drift at the surface. It retains the distinctive features of youth such as moraines, eskers, kames and lakes. The margins of this ice-sheet were very lobate, the lobes having resulted from the extension of the ice at somewhat different times from the Labrador, Keewatin and intermediate centers. Several substages of the Wisconsin have been recognized, the youngest of which reached its maximum development in Iowa and the Dakotas. The depth of leaching since the retreat of the Late Wisconsin ice from Iowa has been determined to be about 30 inches.

Need of Revision of Pleistocene Classification

GENERAL STATEMENT

And now having clearly in mind both the history of development of our present classification of the Pleistocene and the interpretations which have been reached as a result of detailed investigations, extending over many years, of the glacial and interglacial deposits, it should not be difficult to answer the two questions which have been raised, namely: Has there been developing in recent years sufficient "shift in viewpoint as one phase or another of the complex subject is emphasized" to warrant revision of our present classification of the Pleistocene Period? And, Does our present knowledge of the origin and history of the glacial and interglacial materials furnish an adequate basis for estimating the probable duration of the Pleistocene Period?

With regard to the first of these two questions it will be recalled that in the early part of this paper the writer expressed the view that the Pleistocene was a sufficiently significant interval of time in the history of the earth to justify its being given the rank of period. Other geologists also have given the Pleistocene this rank, but more geologists, perhaps, have given the Pleistocene a lesser rank, that of epoch. As previously stated also, it is here proposed to recognize in the classification of the Pleistocene Period two lesser time divisions, namely, epochs and ages, and two equivalent rock terms, series and stages. This is in accordance with well established custom in the classifications of pre-Pleistocene

periods of geologic time. But if the Pleistocene is to be divided into epochs (series) and these again into ages (stages) satisfactory reasons should be given for the adoption of such a policy.

The published record shows that there has been no uniformity of usage of the term epoch, and that the term stage, which in pre-Pleistocene classification is a subdivision of rocks, is not limited to this usage in Pleistocene discussion. It is used frequently as a time term. Lack of precise usage is a defect of classification.

When the most significant facts of known Pleistocene history are analyzed critically from the standpoint of what might be considered to be a logical classification of this period, it is evident that from the beginning of the advance of the first ice-sheet to the retreat of the last ice-sheet there were recurrences of similar geologic events with accompanying similar geologic results. In other words, there were within the limits of the Pleistocene Period a succession of cycles, the most distinct evidences of which are recorded in the deposits which were made during each cycle and in the changes which these deposits underwent before the coming of the succeeding cycle. The records of the glacial and interglacial ages of the different cycles are strikingly similar in many respects but unlike in some respects.

CYCLES OF THE PLEISTOCENE

The oldest cycle of the Pleistocene began with the advance of the Nebraskan ice-sheet and ended with the oncoming of the second ice-sheet, the Kansan. The deposits of the glacial age of this cycle were the Nebraskan drift with associated sands and gravel. During the interglacial age of this cycle, the Aftonian age, those parts of the Nebraskan drift that were so situated topographically throughout the age that they were not subjected to erosion, underwent profound chemical changes. The most widespread and significant product of this weathering of Nebraskan till is Nebraskan gumbotil and related weathered materials, mesotil and silttil (see figure 2). The Nebraskan drift of Nebraskan glacial age and the Nebraskan gumbotil and related weathered profiles of Aftonian interglacial age are so intimately associated in the field that it is necessary that both of them be studied together in order to determine fully the characteristics, distribution, origin, and history of each of them. In this respect the Nebraskan drift and the Nebraskan gumbotil and related weathered materials may properly be considered as constituting a unit of the Pleistocene—the chief sedimentary record of the first cycle.

The second cycle began with the advance of the Kansan ice-sheet and terminated with the oncoming of the third ice-sheet. During the Kansan

glacial age of this cycle, the Kansan drift, which in many places is similar to the Nebraskan drift of the first cycle, was deposited; and during the Yarmouth interglacial age of this cycle the Kansan gumbotil and related weathered materials were developed widely, where the conditions were similar topographically and in other respects to the conditions which produced the Nebraskan gumbotil in the Aftonian interglacial age of the first cycle (see figure 3). This Kansan gumbotil, which was developed by chemical weathering during the Yarmouth interglacial age, is thicker than the Nebraskan gumbotil developed in the Aftonian interglacial age of the first cycle. This and other facts indicate that the Yarmouth age was of greater duration than the Aftonian age. As in the case of the Nebraskan drift and Nebraskan gumbotil, the Kansan drift and Kansan gumbotil constitute a sedimentary unit of the Pleistocene.

The third cycle of the Pleistocene began with the recurrence of glacial conditions which resulted in the third ice-sheet. In this third cycle, the Illinoian drift was deposited during the glacial age of the cycle and the Illinoian gumbotil and related weathered materials were developed by chemical action during the Sangamon interglacial age. Recent studies in Illinois and in southeastern Iowa have shown that the Illinoian gumbotil and related weathered profiles are as widespread as are the poorly drained Illinoian uneroded uplands. The Illinoian gumbotil is not as thick as the gumbotil on the older drifts. Before the close of the Sangamon interglacial age of the third cycle, loess was deposited in places on the Illinoian gumbotil and elsewhere on the eroded surfaces of the Illinoian and older drifts. Where the late Sangamon loess was not deposited on the Illinoian gumbotil the development of gumbotil was continuous throughout Sangamon time. The Illinoian drift and the Illinoian gumbotil constitute a third sedimentary unit of the Pleistocene.

From the facts presented it is evident that in the first, second, and third cycles strikingly similar records were made. During each of the glacial ages drift was deposited and each of the three interglacial ages was sufficiently long for the development of widespread gumbotil and related materials by chemical weathering of the drift. Furthermore, during each of the interglacial ages where the conditions were unfavorable for gumbotil development erosion was effective and in places the gumbotil itself was eroded before the end of the cycle. In some places sands and gravels, and in other places loess were deposited during the interglacial ages, and in still other places, under favorable conditions, peat was formed. But the gumbotils, on account of their distinct characters, definite topographic positions, and distributions, have proved to be

more useful than other criteria in differentiating and mapping the three oldest units of the Pleistocene. In other words, the gumbotils make possible the application of stratigraphic methods in correlating and mapping the three oldest drifts.

There remains to be discussed that part of the Pleistocene which began with the advance of the Iowan ice-sheet and ended with the retreat of the Wisconsin ice-sheet. As stated previously, the Recent age is being considered here not as a part of an incomplete cycle of the Pleistocene, as might be defended from some standpoints, but, somewhat arbitrarily, as an age which followed the Pleistocene.

During the time from the beginning of the Iowan to the beginning of the Recent age there were three ages, the Iowan glacial age, the Peorian interglacial age, and the Wisconsin glacial age. During the Iowan age drift was deposited, during the Peorian age a widespread loess was formed, and during the Wisconsin age the Wisconsin drift was laid down. It now seems clear that the Peorian loess, which in Iowa distinctly separates stratigraphically the Iowan drift below from the Wisconsin drift above, is related closely in age to both these drifts. Moreover, several glacial geologists are convinced that the Peorian loess is related genetically in part to the Iowan drift and probably in part also to the Early Wisconsin drift. The relationships of the Peorian loess to the Iowan and Wisconsin drifts have been emphasized in a recent paper by the writer.[5]

The prevailing climatic conditions during the time of the deposition of the Peorian loess have not been established. Some fossils in the loess have been interpreted as demanding conditions as temperate as the conditions of the present time. However, it may be that the faunas which lived during the time of loess deposition were able to adapt themselves to varying climatic conditions of considerable range.

The results of the most recent investigations of the Iowan, the Peorian, and the Wisconsin ages [6] suggest strongly that the Iowan glacial age and the Peorian interglacial age do not constitute a cycle independent of the succeeding Wisconsin glacial age, but that all three taken together may more properly be included in a single cycle, although one which involved a much shorter time than that covered by the earlier cycles.

If the foregoing interpretations are justified from the evidence, then Pleistocene time may be thought to have involved four cycles. The first

[5] G. F. Kay: The relative ages of the Iowan and Wisconsin drift-sheets. Amer. Journ. of Science, vol. 21, February, 1931, pp. 158-172.

[6] G. F. Kay: Op. cit.

of these cycles included the Nebraskan glacial age and the Aftonian interglacial age; the second cycle included the Kansan glacial age and the Yarmouth interglacial age; the third cycle included the Illinoian glacial age and the Sangamon interglacial age; and the fourth cycle included the Iowan glacial age, the Peorian interglacial age, and the Wisconsin glacial age. Some geologists may wish to include the Recent age as a part of this cycle. The Peorian age was so short in comparison with earlier interglacial ages and the deposits made during this age are so closely related to the deposits of the Iowan and Wisconsin ages that it would seem proper to consider all three of these ages as phases of one cycle rather than to consider the Iowan glacial age and the Peorian interglacial age as belonging to one cycle and the Wisconsin as a glacial age of a succeeding independent cycle.

PROPOSED CLASSIFICATION

A satisfactory classification of the Pleistocene should have woven into it, insofar as conditions will permit, the fundamental concepts which have been generally accepted by glacial geologists, and from time to time as new concepts gain favor the classification should be revised. Those parts of the existing classification which continue to serve a useful purpose should always be conserved.

It would seem to be desirable at the present time, in the light of detailed knowledge of the characteristics, origins, and histories of glacial and interglacial deposits, to bring together for distinct recognition in Pleistocene classification the sedimentary units which were the chief products of the cycles of the Pleistocene to which reference has been made. If this were done the cycles would appropriately be designated epochs, and the sedimentary units, each of which consists of the intimately associated glacial and interglacial materials formed during an epoch, would logically have the rank of series.

On the basis of the viewpoints just stated it is here proposed to revise our present classification of the Pleistocene by introducing four epochs (series), each of which will be given an appropriate name. The divisions are based on the sedimentary record. The three oldest epochs (series) will each include a glacial age (stage) and an interglacial age (stage). The fourth or youngest epoch (series) will differ from the other three in that it will include three ages (stages), two of which are glacial, the third a very short interglacial age (stage) separating the two glacial ages (stages).

The revised classification is as follows:

Period (System)	Epoch (Series)	Ages (Stages) (Recent)	Substages
Pleistocene or Glacial	Eldoran	Wisconsin	
		Peorian	
		Iowan	
	Centralian	Sangamon	
		Illinoian	
	Ottumwan	Yarmouth	
		Kansan	
	Grandian	Aftonian	
		Nebraskan	

In this classification the Pleistocene Period (system) includes four epochs (series) and nine ages (stages). If in the future it should seem wise to include the Recent Age (stage) in the Eldoran Epoch (series) there would be ten ages (stages) in the Pleistocene. The ages (stages) continue to have the well established names of our present classification. Names are not here given for the substages of the Wisconsin stage which have been described recently by Leverett [7] and to which presumably he will soon give appropriate names. New names have had to be chosen for the four epochs (series) and these names have been taken from localities where the materials of the different stages have been studied in all their relationships and where they have areal distribution. A Pleistocene map of the Mississippi Valley (figure 6) shows the distribution of the stages of the four series. That part of the map outside the boundaries of Iowa was prepared chiefly from maps by Antevs which appeared recently in the Bulletin of the Geological Society of America, Volume 40, pages 644-645, 1929. Figure 7 is a diagram which represents the relationships of the different series and stages of the Pleistocene of the Mississippi Valley.

Study of the Pleistocene map shows that the name Grandian comes from the Grand River Valley of southwestern Iowa. Here the Nebraskan

[7] Frank Leverett: Moraines and shorelines of the Lake Superior region. U. S. Geol. Survey, Prof. Paper 154A, 1929, pp. 1-72.

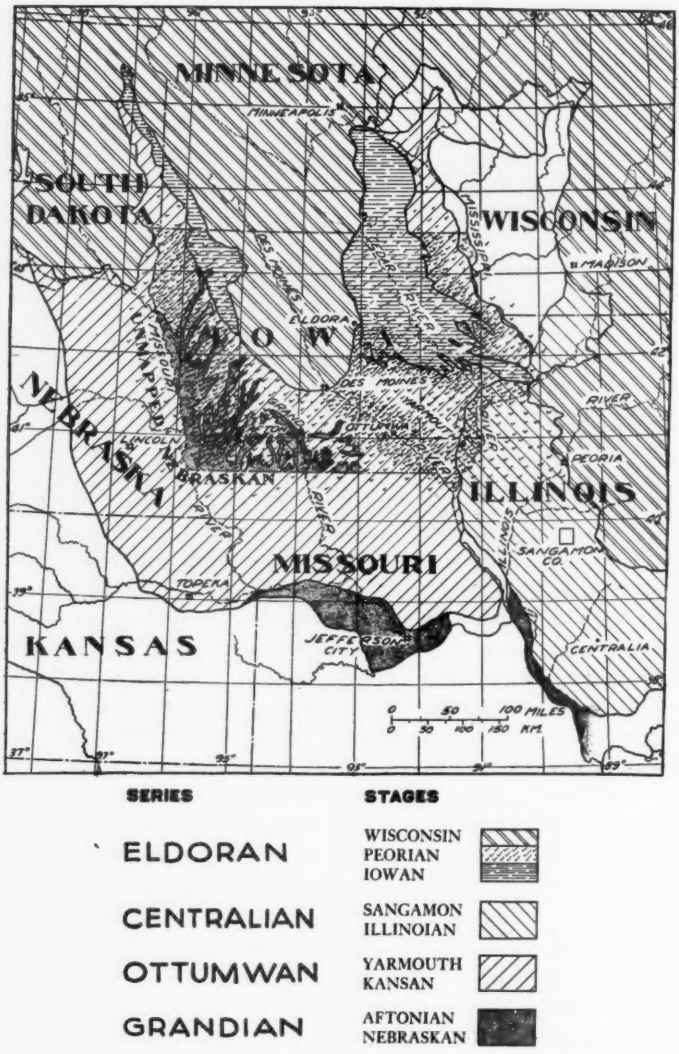

FIGURE 6.—*Pleistocene Map of the Mississippi Valley*

Showing the distributions of the stages of the four series. The Peorian loess in Iowa is shown (see check marks) overlying the Nebraskan, Kansan, Illinoian, and Iowan drifts.

glacial stage and the Aftonian interglacial stage have been studied in detail.[8] The name Aftonian was chosen many years ago from Afton, a town in this area. The name Ottumwan comes from Ottumwa, a city in southern Iowa. Ottumwa is situated within a large area in which the Kansan drift in all its aspects has been studied and described, and in which on the Kansan till the Kansan gumbotil, Yarmouth in age, is typically developed.[9] Centralian comes from Centralia, a town in Marion County of south-central Illinois. In a large area surrounding Centralia the Illinoian till and Illinoian gumbotil are well developed. The members of the Illinois Geological Survey have found unusually fine sections of the Centralian series along an Illinois Central Railroad cutoff, made in recent years in eastern Marion County.[10] Eldoran has been chosen from Eldora, a town in Hardin County, Iowa. Within a small area in the vicinity of the type locality the characteristics and

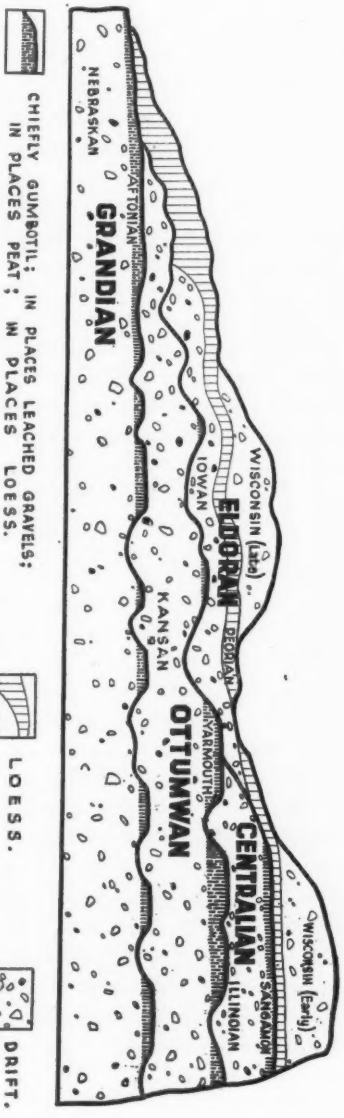

FIGURE 7.—*Diagram showing Relationships of the Series and Stages of the Pleistocene in the Mississippi Valley*

[8] G. F. Kay and E. T. Apfel: The Pre-Illinoian Pleistocene geology of Iowa. Iowa Geol. Survey, vol. xxxiv, 1929, chapters iv and v.

[9] G. F. Kay and E. T. Apfel: Op. cit., chaps. vi and vii.

[10] M. M. Leighton and Paul MacClintock: Weathered zones of the drift-sheets of Illinois. Jour. Geol., 38, 1930, pp. 39-40.

relationships of the Eldoran series—the Iowan drift, the Peorian loess, and the Wisconsin drift—have been studied and mapped as distinct formations [11] (see figure 6). It will be seen, therefore, that each locality chosen is typical of the cycle it represents.

Duration of the Pleistocene Period

General statement

And now the second question will be considered:

Does our present detailed knowledge of the origin and history of glacial and interglacial materials furnish an adequate basis for estimating the probable duration of the Pleistocene Period?

Many geologists have evinced a keen interest in the problem of estimating the duration of the Pleistocene or Glacial Period. The similarity of processes and products of the present day to those of immediately preceding ages of earth's history, and the accessibility of the products and their comparatively slight alteration have invited repeated attempts to deduce time values in terms of years.

Early estimates

In the earlier attempts, the problem was considered to be a relatively simple one and the results were stated boldly and confidently. But as the time estimates derived by different methods proved to be widely discordant and students gained wider familiarity with the phenomena, estimates were put forward with greater caution, and wider limits of possible error were recognized. Concomitantly with this increasing recognition of the complexity of the problem has come also, in general, an increase in the time estimates, not only of the whole glacial period but also of specific intervals. The result has been that in recent years the estimates of the duration of the Pleistocene have been much larger than the estimates of earlier years.

One of the greatest difficulties in the estimation of time from the results of geological work done during an interval is the lack of precise data as to the rate at which similar work is being done at the present time. And even when the present rate is known, it is impossible to determine how nearly similar a rate obtained in the past.

Many kinds of data have been used in estimating the duration of glacial

[11] S. W. Beyer: Geology of Hardin County, Iowa. Iowa Geol. Survey, vol. x, 1899, pp. 280-285.

and interglacial ages of Pleistocene time. Among these may be mentioned:

1. Volumes of stratified or unstratified drift. Rates of deposition of such materials are very imperfectly known, but a consideration of relative volumes of materials deposited by different ice-sheets or during interglacial ages may be of some value in determining approximate relative durations.

2. Amount of vegetable growth and humus accumulation, as shown by forest beds and old soil zones. These phenomena may be estimated roughly and may have some relative value.

3. Climatic changes as indicated by changed faunas and floras. The rate of change of climate is little known, and until more is discovered on this subject, time estimates based on climatic change have little more than speculative value.

4. Amount of erosion of preexisting topography by ice. Both the amount and the rate of erosion are difficult to determine, but the method may have some value in some cases.

5. Amount of surface erosion of glacial deposits. The amount is here rather readily determined in many places, but the rate is difficult to deduce. The method is, however, of considerable value in determining relative durations and antiquity of deposits which are exposed areally for study.

6. Extent of cutting of special gorges and retreat of falls. This method is one which has been extensively used and permits of relatively valid estimates. The variation of rates of cutting at different stages is difficult to ascertain, and even in this method results have varied widely.

7. Strength of beach features such as terraces and cliffs cut by glacial lake waters. These data permit estimates of relative duration which are of considerable value.

8. Decomposition of pebbles and boulders. Relatively little is known of absolute rates in the case of this process, but the method shows considerable possibilities if attacked quantitatively.

9. Rates of migration of plants and animals. Evidence of this sort has yielded only unimportant results, but seems likely to permit important conclusions when sufficient biological data are available.

10. Degree and extent of oxidation. Recent studies have shown that oxidation proceeds relatively rapidly but that it is rather unimportant as compared with leaching of calcium carbonate.

11. The counting of annual layers of clay (varves) in glacial lakes and valleys. The use of varves has been developed by De Geer and his as-

sistants in Sweden and by Antevs in America. This method gives a reliable chronology for available parts of the records of the retreat of the last ice-sheet.

12. Degree and extent of leaching of calcium carbonate in similar materials similarly situated topographically and climatically.

The estimates which have been made by investigators by using the different criteria to which reference has just been made will be introduced here only insofar as they contribute to the judgments now to be developed by the writer regarding Pleistocene duration.

Estimates of the duration of the Pleistocene or Glacial Period have fallen into two general classes, as has been frequently pointed out: (1) Efforts to estimate the relative durations of the several glacial and interglacial ages and (2) efforts to measure in years the interval since the close of the glacial period.

BASIS OF PRESENT ESTIMATES

In this paper the estimate of post-Wisconsin time will be taken from the best consensus of opinion at the present time from the most reliable data. Starting with the assumption that post-Wisconsin time in Iowa has been established with sufficient definiteness to be used with confidence as a standard unit, data will be presented for computing the minimum time involved in each of the glacial and interglacial ages of the Pleistocene and of the Period as a whole.

The evidence to be used in this paper in estimating the durations of the interglacial ages will involve chiefly the results of field studies in Iowa of the relative depths of leaching of calcium carbonate in similar materials, similarly situated topographically and climatically. In determining the durations of glacial ages use will be made of the criteria that have seemed to be the most dependable in estimating the duration of the last glacial age—the Wisconsin.

In a recent paper [12] the writer presented the results of studies of the relative depths of leaching of primary calcium carbonate (limestone pebbles and comminuted limestone flour) in the areas of Iowan and Wisconsin drifts and related deposits of Iowa. In these studies it was assumed that if the depths of leaching of primary calcium carbonate could be determined under comparable conditions in the two areas then the relative ages of the two drifts could be established. The comparable conditions of leaching in both areas involved: (1) Materials of similar

[12] G. F. Kay: Relative ages of the Iowan and Wisconsin drift-sheets. Amer. Jour. Sc., vol. 21, February, 1931, pp. 158-172.

composition, texture, and degree of compactness; (2) similar topographic conditions, namely, uneroded uplands where no material had been added throughout the time of leaching; in other words, the materials being compared were leached under similar drainage conditions; and (3) the selection of upland prairie areas rather than forested areas, care being taken to select only those places which had not been submerged throughout the period of leaching. It seemed proper to assume that since the areas studied were comparatively close together, the climatic factors had been fairly similar throughout the time that the leaching processes had been in action. It is recognized, of course, that the rate of leaching has varied with changes in climate, the rate being slower under glacial than under interglacial conditions. But it is doubtful if the differences in rate were of sufficient range to modify the results to any important extent.

The results were most interesting and must be emphasized here as similar criteria will be used in this paper in estimating the durations of interglacial ages which are pre-Iowan in age.

LEACHING OF GLACIAL DEPOSITS

It was found that within the Iowan drift area of northeastern Iowa (see figure 6) the Iowan till, where not overlain by loess, is leached to a depth of approximately 5 feet 6 inches. In the same area, the depth of leaching of upland Iowan gravels, where these are not overlain by loess, is about the same; and in the few places found within this Iowan area where the upland loess is of sufficient thickness to extend below the leached zone the depth of leaching does not differ noticeably from the depth of leaching of the upland Iowan till or the upland Iowan gravel. Furthermore, the combined leaching of loess and till where both materials are in the leached section is between 5 and 6 feet; in fact, the average combined leaching of the loess and till in more than twenty sections was found to be 5 feet 6 inches. The combined leaching of loess and gravels, where both are in the leached section, is somewhat less than 6 feet.

The uniform depth of leaching of Iowan till, of Iowan gravels, of Peorian loess, of loess and till together in section, and of loess and gravel together in section is a striking fact. All of the materials apparently began to be leached at about the same time and the leaching under similar topographic and climatic conditions has proceeded downward to the present time at approximately the same rate.

The studies of leaching within the Des Moines lobe of the Late Wisconsin drift area in Iowa showed that the depth of leaching of calcium carbonate is about 2 feet 6 inches; and it was found that the average depth

of leaching of upland Wisconsin gravels was essentially the same as for the till.

From these studies of leaching of similar materials, similarly situated topographically and climatically, within the Iowan and Wisconsin drift areas of Iowa it was demonstrated that the average depth of leaching of Iowan till which has never been covered by later deposits is somewhat more than 5 feet, and the average depth of leaching of Late Wisconsin till is approximately 2 feet 6 inches. Also the average depths of leaching of upland Iowan gravel and upland Late Wisconsin gravel are little more than the average depths of leaching of Iowan till and Wisconsin till, respectively. From these facts it is clear that the depth of leaching in upland till and in upland gravel of Iowan age is somewhat more than twice the depth of leaching in upland till and in upland gravel of Wisconsin age.

Keeping these facts in mind with regard to the relative depths of leaching of calcium carbonate in Iowan till and gravel and in Late Wisconsin till and gravel the results of field studies, extending over many years, of the depths of leaching of calcium carbonate in drifts older than the Iowan will be critically examined.

In the discussion in the earlier part of this paper of the three oldest drifts in Iowa—the Nebraskan, the Kansan, and the Illinoian—it was emphasized that gumbotil had been developed by chemical weathering on all three of them. It has been well established that gumbotil is formed only on flat, poorly drained areas of ground moraine. Under such topographic conditions chemical weathering is effective but erosion is negligible. It has been shown that the Nebraskan gumbotil has an average thickness between 8 and 9 feet, the Kansan gumbotil a thickness more than 11 feet, and the Illinoian gumbotil a thickness between 4 and 6 feet. There is no gumbotil on the Iowan or Wisconsin tills, even where the topographic conditions are favorable, because they have not been subjected to weathering for a sufficiently long time to be altered to gumbotil. The development of gumbotil from unoxidized and unleached till requires a comparatively long time under proper topographic conditions.[13]

As soon as a drift became exposed after the retreat of an ice-sheet marginal vegetation undertook almost at once to occupy the new territory, and

[13] G. F. Kay and J. N. Pearce: The origin of gumbotil. Jour. of Geol., vol. xxviii, 1920, pp. 89-125.

G. F. Kay and E. T. Apfel: The Pre-Illinoian Pleistocene geology of Iowa, vol. xxxiv, Iowa Geol. Survey, 1929, pp. 139-141.

M. M. Leighton and Paul MacClintock: Weathered zones of the drift-sheets of Illinois. Jour. of Geol., vol. xxxviii, 1930, pp. 28-50.

as soon as the climatic conditions became sufficiently congenial this vegetation no doubt spread rapidly over the surface. Even before the coming of vegetation wind and rain, sun and frost, and other weathering agencies had begun to alter the newly exposed glacial drift. The air and water oxidized the iron compounds in the drift and changed the color from the drab or gray of the fresh drift to the yellow, brown and red colors of iron oxides. As the oxidation extended downward from the surface other changes followed. The underground water began to dissolve those rock minerals which were the most soluble, and as the water passed downward the soluble materials were carried from the soil into the subsoil. Thus, limestone and other calcareous materials were leached out, first from the surface zones and then from deeper and deeper horizons. Oxidation extended itself downward much more rapidly than did leaching, and hence in the course of time the unchanged fresh till had two zones developed above it, the oxidized, unleached zone and the overlying oxidized and leached zone. But the maximum change had not yet been reached. Vegetation was growing on the surface and the vegetal products of previous seasons were undergoing decay. Organic acids were formed, which, together with the other agents of weathering, brought about additional chemical changes. The result was a reversion to the darker colors of reduced iron compounds, the breaking down of fine materials into still finer—with many of them reduced to colloidal size—and the disintegration and decomposition of many of the complex minerals of which the drift is composed. Thus gumbotil and related underlying zones were formed (see figure 8).

Where gravels underwent chemical weathering throughout the time of gumbotil development from till and under topographic and climatic conditions similar to those under which the till became gumbotil they too became profoundly weathered, to depths greater than the thicknesses of the gumbotils.

Sufficient records are now available to warrant some generalizations regarding the depths of leaching of upland gravels on each of the five drifts, the Nebraskan, the Kansan, the Illinoian, the Iowan, and the Wisconsin. In other words, the relative depths of leaching of calcium carbonate are known for gravels whose times of deposition have been definitely determined. For example, sections have been studied of weathered Nebraskan gravels which have the same topographic position as Nebraskan gumbotil and which were subjected to weathering throughout the Aftonian interglacial age. In places these gravels are overlain by unleached Kansan till and hence they have undergone no additional weathering since the

close of Aftonian time. The depth of leaching of Nebraskan gravels comparable in age to the Nebraskan gumbotil is about 20 feet. The best-known section of such gravels in Iowa has been described by Schoewe.[14]

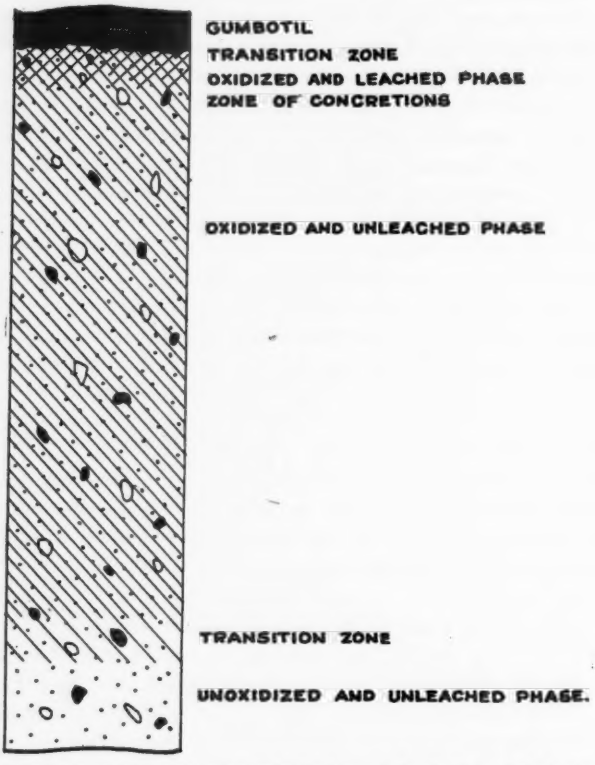

FIGURE 8.—*Diagram showing Relationships of Gumbotil to underlying Till Zones*

Sections are known also of Kansan gravels which have the same topographic position as Kansan gumbotil of Yarmouth age and which underwent chemical weathering throughout Yarmouth interglacial time. They have undergone no additional weathering because since the close of the

[14] W. H. Schoewe: The interpretation of certain leached gravel deposits in Louisa and Washington counties, Iowa. Proc., Iowa Acad. Sci., vol. xxvi, 1919, pp. 393-398. G. F. Kay and E. T. Apfel: The Pre-Illinoian Pleistocene geology of Iowa. Iowa Geol. Survey, vol. xxxiv, 1929, pp. 203-204.

Yarmouth age they have been protected from weathering by overlying unweathered Illinoian drift. The depth of leaching of these Kansan gravels is about 30 feet. The best known section has been described.[15] Further study of this section, including boring beneath the base of the exposure, showed 30 feet of leached gravels and silts underlain by unleached till.

Good sections of Illinoian gravels which have the same topographic position as Illinoian gumbotil and which underwent weathering throughout Sangamon interglacial time have been difficult to find either in Illinois or in Iowa. A section in the vicinity of Sparta in southern Illinois shows more than 12 feet of leached Illinoian gravels below leached Peorian loess. Other sections in Illinois and in Iowa are sufficiently satisfactory to warrant the judgment that the Illinoian upland gravels where they were not overlain by late Sangamon loess were leached as much as 12 feet before the deposition of Peorian loess.

No sections of Iowan drift overlying the upland Illinoian gravels are known, but since the Peorian loess which overlies the leached Illinoian gravels is thought by the writer and some other glacial geologists, including Alden and Leighton, to be but little younger than the Iowan drift the leaching of the gravels may be interpreted to have taken place in Sangamon time.

As already stated in this paper, the Iowan gravels where not overlain by Peorian loess or by Wisconsin drift have been leached about 5 feet 6 inches, practically the same as the Iowan till, and the Peorian loess where it lies on Iowan drift and has not been overlain by Wisconsin drift also has been leached to about the same depth as the Iowan till. The Wisconsin upland gravels, as stated also, are leached to 2½ feet.

The facts just presented may be summarized as follows: Nebraskan upland gravels were leached and otherwise weathered during Aftonian time to a depth of 20 feet; Kansan upland gravels during Yarmouth time to a depth of 30 feet; Illinoian gravels during Sangamon time to a depth of 12 feet; Iowan upland gravels during post-Iowan time to a depth of 5 feet 6 inches, and Late Wisconsin upland gravels during post-Wisconsin time to a depth of 2 feet 6 inches. Now if we compare these amounts of leaching with the amounts of time involved and if post-Wisconsin time be designated as unity then post-Iowan time would be represented by 2.2, Sangamon time by 4.8, Yarmouth time by 12, and Aftonian time by 8.

[15] G. F. Kay and E. T. Apfel: Op. cit., pp. 148-149.

TIME INVOLVED

How can these units be interpreted in terms of years? If the time since the retreat of the Late Wisconsin could be established the answer would seem to be a relatively simple one. It would seem to be a safe judgment in the light of recent investigations to assign 25,000 years to the time since the retreat of the Late Wisconsin ice-sheet from Iowa. When this figure was submitted recently to Antevs and to Leverett for their judgment as to the advisability of my adopting it in this paper both of them expressed the view that, based on present evidence, 25,000 years is, perhaps, the time estimate that can best be defended. Using then 25,000 years for post-Late Wisconsin time in Iowa, post-Iowan time would be 2.2 times this figure or 55,000 years, Sangamon time 4.8 times 25,000 years, that is, 120,000 years, Yarmouth time 12 times 25,000 years, which makes 300,000 years, and Aftonian time eight times the post-Late Wisconsin time, that is, 200,000 years. The combined durations of Aftonian, Yarmouth, and Sangamon interglacial ages, and of post-Iowan, total about 675,000 years.

In arriving at these estimates it has been assumed that leaching of calcium carbonate proceeds downwards in gravels at a uniform rate from the surface to depths of 30 feet and more. If the rates of leaching decrease with increase in depth of leaching, as is probably the case but can not be proved, then the figures just used would have to be increased relative to one another. The figures based on uniform rates of leaching at increasing depths would certainly be trustworthy for estimating minimum duration.

Thus far only interglacial time in Iowa has been estimated. The problem now is: How can length of glacial time in Iowa be determined? How long were ice-sheets within the limits of Iowa? It is clear that so long as ice-sheets were present over any area in Iowa there could be no leaching of the materials buried beneath the ice-sheets. The boundaries of the different drift-sheets have been mapped with sufficient accuracy to enable fairly definite statements to be made with regard to the distances each of the ice-sheets advanced southward beyond the latitude of the north boundary of Iowa. If in addition the rates of advance and of retreat of the different ice-sheets were known, and also the time involved in the development of terminal and recessional moraines, it would be comparatively easy to reach a fairly definite judgment as to the duration of the glacial ages in Iowa.

Recent investigations by De Geer and his assistants in Sweden and by Antevs and others in America have shown fairly definitely for the areas

studied that the Wisconsin ice-sheet retreated at the rate of about one mile in ten years. If this rate is accepted in connection with the retreat of the Late Wisconsin drift-sheet in Iowa and the same rate is used for the advance of this ice-sheet into Iowa then it is not difficult to estimate the time involved in the advance and retreat of this ice-sheet. There are no data available with reference to the time involved in the development of moraines, and hence in attempts to establish minimum estimates it will be assumed that the ice-sheet began to retreat as soon as it had advanced to the southernmost point of the moraine. If the same methods are used in connection with each of the ice-sheets which invaded Iowa the durations of these ice-sheets in Iowa can be calculated. The combined estimates for the interglacial ages and the glacial ages will furnish the estimate of Pleistocene duration in Iowa.

The Late Wisconsin ice-sheet advanced into Iowa a distance of about 150 miles. If the rate of advance is considered to have been one mile in ten years then the time of advance involved about 1,500 years. If the same length of time was taken for the retreat then the Late Wisconsin ice-sheet had a minimum duration in Iowa of about 3,000 years. By the same method it can be estimated that the duration of the Iowan was about the same as the Late Wisconsin, of the Illinoian, which advanced more than 450 miles southward from the latitude of the north boundary of Iowa, about 9,000 years, and of the Kansan and Nebraskan each about 7,500 years. The combined durations of the glacial ages may be taken to have been about 30,000 years. When this figure is added to the 675,000 years, to which reference has already been made, a minimum duration of about 700,000 years is obtained for the whole Pleistocene in Iowa.

In order that the methods just outlined for arriving at the minimum duration of each of the glacial and interglacial ages in Iowa and of the Pleistocene Period as a whole may be readily understood a diagram has been prepared (figure 9). A study of this diagram will reveal the relative depths of leaching of upland gravels on the different drift-sheets within the areas where the best sections are known. At the left of the diagram is a graph showing the approximate distances which the different drift-sheets advanced beyond the latitude of the north boundary of Iowa; also the estimates of the durations of glacial and interglacial ages in Iowa are plotted in accordance with the data which have been discussed in this paper. The most striking fact is the great length of time involved in the interglacial ages in Iowa in contrast to the duration of the glacial ages. The total minimum duration in Iowa is seen to approximate 700,000 years.

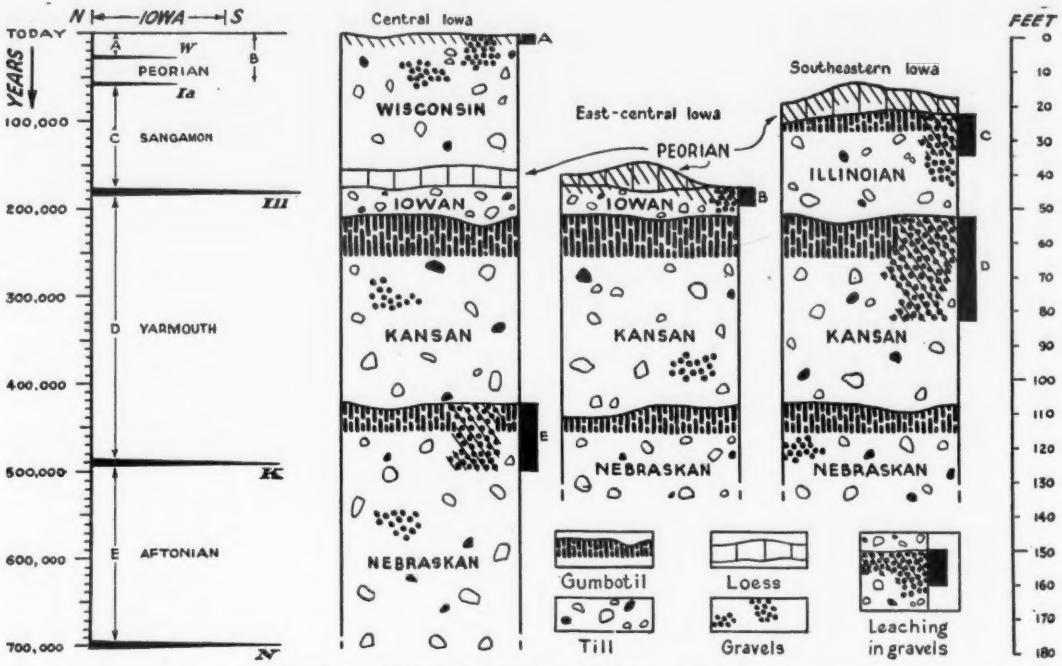

FIGURE 9.—*Minimum Duration of Pleistocene Period in Iowa*

Based on relative depths of leaching in upland gravels. The diagram indicates relative depths of leaching of upland gravels in Iowa and the estimates of minimum duration of glacial and interglacial ages and of the Pleistocene Period as a whole.

Time involved in Gumbotil Development

It has been emphasized in this paper that in the upland Iowan till and upland Iowan gravels the depth of leaching is approximately the same, namely, about 5 feet 6 inches, and that there has been insufficient time since weathering began on the Iowan till for gumbotil to be developed. On the other hand, Illinoian upland gravels have been leached to a depth of about 12 feet, and about 5 feet of gumbotil has been developed on the Illinoian till. When these and other facts are analyzed carefully the judgment is reached that the gumbotil phase of weathering begins to appear on till soon after leaching of calcium carbonate has extended downward from the surface to a depth of somewhat more than 5 feet. If the upland Illinoian till and similarly situated Illinoian gravels were leached somewhat more than 5 feet when gumbotil began to be formed on the Illinoian leached till then the 5 feet of Illinoian gumbotil was developed on the till from the surface downward during the time that an additional 7 feet of leaching in Illinoian gravels took place below the 5 feet which had been previously leached (see figure 9). Again, the thickness of Kansan gumbotil on Kansan till is about 12 feet and the depth of leaching of Kansan upland gravels about 30 feet, 5 feet of which are interpreted to have been leached before gumbotil development began. In this case, 12 feet of gumbotil was formed during the time of leaching of 25 feet of Kansan gravels. Furthermore, the thickness of Nebraskan gumbotil on the Nebraskan till is about 8 feet, and the depth of leaching of Nebraskan gravels is about 20 feet, 5 feet of which were presumably leached before the gumbotil began to be formed. Hence, during the formation of 8 feet of Nebraskan gumbotil about 15 feet of additional leaching of Nebraskan gravels took place.

These facts indicate that as gumbotil thickens the length of time involved in the development of each additional foot is relatively longer than the time involved in the leaching of each additional foot of gravels. In other words, with increasing thickness gumbotil is formed progressively more slowly than gravel is leached. Thus while 5 feet of gumbotil was formed 7 feet of gravel was leached beneath 5 feet of gravel already leached, while 8 feet of gumbotil was formed 15 feet of gravel was leached beneath 5 feet of gravel previously leached, and while 12 feet of gumbotil was being developed the leaching of gravels was extended downward 25 feet beneath 5 feet of overlying leached gravels.

The minimum time involved in the development of the gumbotil on each of the three tills—the Nebraskan, the Kansan, and the Illinoian—

can be estimated from the known data. The gumbotils developed in each of the interglacial ages, the Aftonian, the Yarmouth, and the Sangamon, only after more than 5 feet of upland gravel had been leached. The leaching of the gravels to this depth at the rate of post-Wisconsin leaching, namely, 2½ feet in 25,000 years, involved in each case about 50,000 years. The time involved in the development of the 8 feet of gumbotil on the Nebraskan till was therefore 50,000 years less than the 200,000 years which has been estimated for Aftonian interglacial time, that is, 150,000 years, for the 12 feet of gumbotil on the Kansan till 50,000 years less than the 250,000 years involved in Yarmouth interglacial time, that is, 200,000 years, and for the 5 feet of gumbotil on the Illinoian till 50,000 years less than the 120,000 years involved in Sangamon interglacial time, that is, 70,000 years. These too are minimum estimates.

Concluding Statements

Deposits of the Pleistocene or Glacial Period have been subjected to detailed study in America for more than fifty years. In the Mississippi Valley in particular the records of this most fascinating chapter in the earth's history have been remarkably well preserved and thoroughly investigated. In fact, this area has been made a classic one as the result of the researches of T. C. Chamberlin, McGee, N. H. Winchell, Leverett, Calvin, and many other geologists. Here evidence has been found which is conceded to be the most reliable in interpreting the history of the Pleistocene, in classifying the deposits of this geological system, and in estimating the duration of the Period.

In this paper the classification and the duration of the Pleistocene Period have been discussed. It was pointed out that when the most significant facts of Pleistocene history are analyzed critically in relation to what might be considered as a logical classification it is evident that from the time of the advance of the first ice-sheet, the Nebraskan, to the retreat of the last ice-sheet, the Wisconsin, there were recurrences of similar geological events with accompanying similar geological results. In other words, there were within the limits of the Pleistocene Period a succession of cycles, the most significant evidences of which are recorded in the deposits which were made during each cycle and in the changes which the deposits underwent before the coming of the succeeding cycle. Reasons were given for the interpretation that Pleistocene history involved four cycles. The judgment was expressed that it would seem to be desirable at the present time to bring together for distinct recognition in Pleistocene classification the sedimentary units which are the chief

products of the cycles, and that the cycles be designated epochs and the sedimentary units, each of which consists of the intimately associated glacial and interglacial materials formed during an epoch, be given the rank of series.

A revised classification of the Pleistocene has been presented. It recognizes four epochs (series), each of which is divided into ages (stages) which continue to have the well established names of the present classification. New names have been chosen for the four epochs (series): Grandian, Ottumwan, Centralian, and Eldoran. These names were chosen from localities where the materials of the different stages have been studied in all their relationships and where they have areal distribution.

Estimates of the minimum duration of the Pleistocene in Iowa have been given. The evidence used in reaching judgments as to the durations of the interglacial ages was gained chiefly from extensive field studies in Iowa of relative depths of leaching of calcium carbonate in similar materials which throughout their times of leaching were similarly situated topographically and climatically. Leached gravels of known ages were compared. The differences in depths of leaching are the results of the differences in lengths of time to which the gravels were subjected to weathering agents. The depth of leaching of upland gravels in the Late Wisconsin drift was determined to be about 2 feet 6 inches. This leaching is the result of exposure to weathering since the retreat from Iowa of the Late Wisconsin ice-sheet, that is, through a period estimated to be about 25,000 years. With this rate of leaching of gravels as a unit estimates were made of the lengths of time involved in the leaching of other gravels of known ages. The results for Iowa as given in this paper are as follows: Post-Late Wisconsin time, 25,000 years; post-Iowan time, 55,000 years; Sangamon interglacial time, 120,000 years; Yarmouth interglacial time, 300,000 years; and Aftonian interglacial time, 200,000 years. The combined durations of Aftonian, Yarmouth, and Sangamon interglacial ages, and of post-Iowan, total about 675,000 years.

The durations of the glacial ages in Iowa were estimated from present-day consensus of opinion as to the rates of advance and retreat of ice-sheets. For the retreat of the Late Wisconsin from Iowa the rate of one mile in ten years was adopted. The same rate was assumed for the advance of this ice-sheet into Iowa and also for the advances and retreats of earlier ice-sheets. The minimum duration of glacial time in Iowa was calculated to be about 30,000 years.

In accordance with the methods of evaluation adopted in this paper minimum interglacial time in Iowa was determined to be approximately 675,000 years, and minimum glacial time in Iowa about 30,000 years, the combined estimates giving for the whole Pleistocene in Iowa a minimum duration of about 700,000 years. How far this estimate of the minimum duration of the Pleistocene falls short of the actual duration can not be determined from reliable quantitative evidence. However, it would seem safe to state that the Pleistocene involved probably a million years, possibly twice this length of time.

Evidence was presented also for the judgment that the 5 feet of gumbotil on the Illinoian till involved in its development about 70,000 years, the 12 feet of gumbotil on the Kansan till 250,000 years, and the 8 feet of gumbotil on the Nebraskan till 150,000 years. Gumbotil development was preceded in all cases by leaching of calcium carbonate.

As investigations of Pleistocene deposits continue into the future better and better standards of measurements will be established, and hence more and more accurate determinations of Pleistocene time will be made. The classification of the Period will no doubt have to be revised from time to time as further refinements of study of glacial and interglacial deposits enable more definite interpretations of their origin and history.

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KAMES AND KAME TERRACES OF CENTRAL MASSACHUSETTS [1]

BY THOMAS C. BROWN

(Read before the Geological Society December 30, 1930)

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INTRODUCTION

The numerous valleys of north central Massachusetts are bordered by more or less continuous terraces at elevations varying from 200 feet above sealevel in the lower part of the Nashua Valley northeast of Pepperell to more than 1,000 feet in the upper reaches of Millers River Valley north of Winchendon. These terraces vary in areal extent from mere discontinuous fringes in some of the valleys to broad sand plains a mile or more in width, such as the plains surrounded by the 260-foot contour south of Ayer and south and east of Shirley village. Many of these terraces have kames associated with them, either broad areas of knob-and-basin topography like that of Bakers Brook Valley east of Fitchburg, or single scat-

[1] Manuscript received by the Secretary of the Society January 5, 1931.

tered hillocks jutting out into the valley like those along Millers River west of Orange.

During the past few years extensive road and concrete construction has brought about the opening of numerous sand and gravel pits in these sand plains and kames. As a result fresh sections of the interior have been opened up on a scale that gives the geologist an unusual opportunity to study the structure of these deposits. From the scores of different pits studied in the past few years, a few typical cases are here selected for careful description, and an attempt is made to explain their origin.

Location of the Kames and Kame Terraces

Jackson Avenue 420-foot terrace

Near the east end of Jackson Avenue, in the eastern part of Fitchburg, an extensive sand and gravel pit furnishes an excellent section of the 420-

FIGURE 1.—*Sand Pit near Jackson Avenue, east of Fitchburg*

This illustration shows a section in the terrace along the western side of Bakers Brook Valley. The top-set beds of coarse gravel are horizontal; the sands and fine gravels beneath them are intricately cross-bedded.

foot terrace on the west side of Bakers Brook. In this pit the working face is approximately 25 feet high. The upper 6 feet is composed of horizontally bedded coarse gravel with numerous pebbles and cobblestones 4 to 6 inches or more in diameter, all well rounded and fresh and nearly all of granite. Beneath this coarse gravel is at least 20 feet of intricately cross-bedded sands and fine gravels. Many of the beds are lens-shaped; others dip at variable angles and in various directions. These dipping beds are frequently truncated and covered by others that are practically

horizontal. Aside from the top bed of coarse gravel, no bed or series of beds shows any consistent or persistent dip in any direction for more than a few feet.

In the same 420-foot terrace, about 200 yards south of this sand pit, another excellent section was exposed by an extensive piece of grading in the northern part of Saint Bernard's Cemetery. In reducing one of the rather abrupt natural terrace slopes to more gentle contours, the whole upper surface over an area of a half-acre or more was excavated by steam shovel and moved down the grade. The part excavated was in some places as much as 15 feet in depth and 50 yards or more in length. Examina-

FIGURE 2.—*Section of Kame Terrace at Elevation of 820 feet, a Quarter of a Mile south of Whitmanville*

This exposure, which is in a road gravel pit, shows clearly that the original bedding has been disturbed by slumping toward the valley since deposition, and that the surface slope is due in part to the settling of the beds and not wholly to erosion.

tions made at different times during the progress of this work showed that the structure of the sand plain here is identical with that of the sand pit farther north. The upper 4 feet or more is coarse horizontally-bedded gravel. Below this come cross-bedded sands and fine gravels, the sands predominating; the beds and lenses of material dip at comparatively low angles, but in almost every direction. There is no dominant direction of dip as in the fore-set beds of a delta; the bedding may better be compared with that characteristic of kames, which has been graphically described as "tumultuously bedded."

KAME TERRACE NEAR WHITMANVILLE

A pit opened for road gravel in a kame terrace at an elevation of 820 feet, a quarter of a mile south of the bridge on the Whitmanville-Gardner road, exposes an excellent section of the terrace. Here again the upper beds are nearly horizontal and composed largely of coarse gravel, and the lower beds are sandy and irregularly cross-bedded. This pit was excavated to the valley margin, and shows clearly the internal structure where the terrace slopes down to join the valley floor (see figure 2). The surface slope is due not to erosion, but largely to the slumping of the beds. This is clearly seen by following the massive bed of fine sand which

FIGURE 3.—*Terrace west of Templeton*

This structure seems to indicate that the terrace was built up to a uniform level with horizontal top-set beds. Then through some unknown cause a portion of the terrace slumped down and the sag was later filled with fore-set beds.

is shown in horizontal position near the right side of the picture. About one-third of the way across the picture this bed is dropped vertically a foot or more by a normal fault; in the next third of the section it dips at a considerable angle; and in the last third it is so disturbed and mingled with material from the overlying bed of gravel that its identity is lost. Erosion may have modified the slope to some extent, but it could not cause this mingling of the beds.

KAME TERRACE WEST OF TEMPLETON

A sand pit opened during the construction of the State road through Templeton disclosed the structure shown in figure 3. This pit is one

mile west of Templeton on the west side of Trout Brook and the south side of the State road, opposite the Templeton Cemetery. Only the upper part of the pit is shown in the figure. The arrangement of beds seems to indicate that this terrace was at one time built up to uniform level with horizontal top-set beds like those described in the previous examples but composed of finer material. Then these horizontal top-set beds sagged into the synclinal structure shown in the figure, and the sag was later filled with fore-set beds, bringing it once more to the terrace level.

KAMES OF MILLERS RIVER VALLEY NEAR ORANGE

On the north side of Millers River, one mile west of Orange, is a kame at an elevation of 560 feet, having the structure shown in figure 4. This

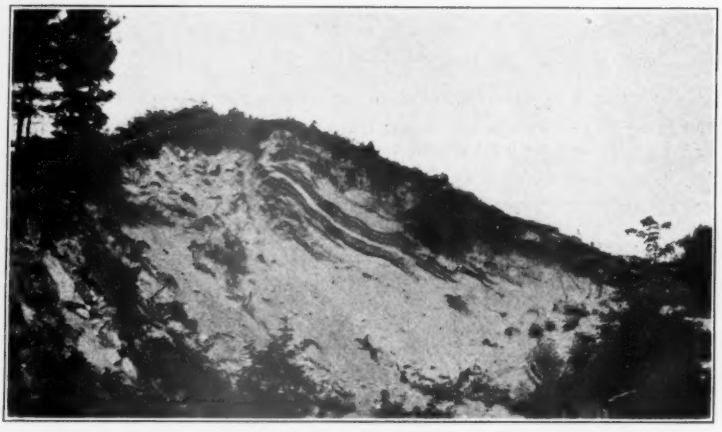

FIGURE 4.—*A Kame Ridge beside the State Road one Mile west of Orange*
This illustration shows how the upper beds have slumped down the side of the kame and become crumpled and bent during the movement.

kame is composed largely of fine sand. The crumpling of the beds, at first glance, suggests pressure due to ice movement, but a careful study of the kame in its natural setting shows that this crumpling is more likely due to the removal of support and consequent slumping.

Half a mile west of this kame, at the same elevation and on the north side of the river but the south side of the road, is the kame shown in figure 5. During the reconstruction of the State road in 1930 this kame was used as a gravel pit and eventually was almost wholly removed. Several visits to the locality during the course of the excavation proved that the structure of this kame was throughout like that shown in figures 5 and

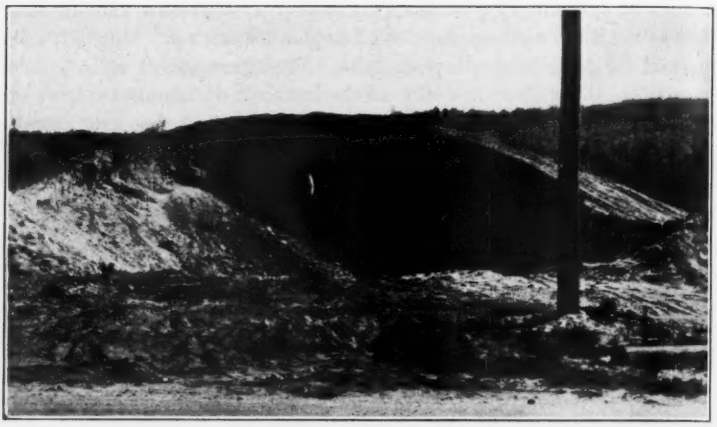

FIGURE 5.—*Gravel Pit in Kame a Mile and a Half west of Orange*

This illustration shows how the internal structure is perfectly preserved in the middle of the kame but has been destroyed by slumping on either side.

FIGURE 6.—*Close-up View of Margin of Kame shown in Figure 5*

This illustration shows the transition from the well-preserved beds of the center to the slumped and disturbed beds of the margin.

6. The upper part of the kame is composed of horizontally bedded coarse gravel top-set beds, approximately 6 feet in depth. Beneath these are beds of sand and fine gravel more or less irregularly cross-bedded but in

places showing a disposition to form fore-set beds either toward the center of the valley or downstream. Some of these fore-set beds are shown near the center of the figure. On the right or downstream side and also on the left or upstream side of this kame the beds have slumped down so that the materials are mingled and the identity of the beds is lost. As excavation proceeded toward the valley this margin of the kame also showed evidence of slumping.

FIGURE 7.—*Gravel Pit in a Terrace west of Templeton*
A great number of large boulders occur in this terrace, causing it to resemble a terminal moraine in composition.

BOULDER-BEARING KAMES AND TERRACES

Although most of the kames and associated terraces are composed largely of well-assorted sands and gravels, a number of them contain occasional boulders and some a great many, in such instances resembling moraines in composition. Figure 7 shows a pit in one of these terraces from which the sand and gravel has been removed for road construction and the boulders left uncovered. Throughout the whole region the terraces and kames show the external features and internal structure described in these typical examples.

TERRACES OF THE SOUTHERN PART OF NASHUA VALLEY

Crosby and Alden have described similar terraces in the southern part of the Nashua Valley. Crosby[2] came to the conclusion, as a result of

[2] W. O. Crosby: Geological history of the Nashua Valley. Tech. Quart., vol. 12, 1899, pp. 312-324.

his studies of the region around the metropolitan reservoir near Clinton, that these sand plains were built out into open lakes in the valley.

"That these high level deposits of modified drift were, in the main, formed in standing water, and only to a limited extent by marginal streams, is indicated by the considerable breadth of the plains at some points, and also by the more or less distinct depression which usually . . . separates the sand plains from the slopes of ledge and till rising above them. . . ."[3]

Alden came to the same conclusion, for he says in regard to the terraces of the Clinton stage of Glacial Lake Nashua:

"Drainage from the ice front contributed much, and the lake waters themselves accomplished more or less erosion of the deposits of the Boylston stage along their shores, so that probably the deposits described above filled the valley from side to side almost if not quite up to water level. Indeed, the lake may have been entirely filled up so that in its place a stream meandered over a broad flood plain. The gravel deposits mark the final stages of the filling."[4]

Both Crosby and Alden believed that the ice-front was a gradually retreating one and had a lobe which projected southwestward in the Nashua Valley. The gradual retreat of this lobe to the northeast uncovered successively lower outlets and gave rise to the successive stages of Lake Nashua. Both authors, however, recognized the existence of water-worked sand and gravel deposits which could not be explained by their theory of lake development. Crosby states:

"My detailed study of the modified drift has not extended over the Groton and Fitchburg quadrangles of the topographic map, and I am not fully prepared to explain the extensive plain or mass of modified drift having a normal height of 400 to 420 feet, lying between the Fitchburg Railroad on the north and the North Nashua River on the south."[5]

Alden also encountered difficulties, for he states:

"North and northwest of Whittemore Hill, however, in the town of Lancaster, partly within the Quinsigamond quadrangle, occur similar pitted delta plains of sand and gravel at altitudes of 300 to 400 feet; that is, at levels somewhat higher than the last of the delta plains south of South Lancaster."

In a footnote he says:

"Professor Emerson states in a personal communication that a study of the area to the north of the Quinsigamond quadrangle has made it appear probable that these deposits are connected with the Clinton stage."[6]

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[3] Crosby: Op. cit., p. 315.

[4] W. C. Alden: The physical features of central Massachusetts. U. S. Geol. Survey, Bull. 760, 1924, p. 66.

[5] Crosby: Op. cit., pp. 323-324.

[6] Alden: Op. cit., pp. 69-70.

TERRACES OF THE NORTH NASHUA RIVER VALLEY

Studies conducted by the writer in the valley of the North Nashua River show that these deposits which troubled Crosby and Alden are of great areal extent and have an important bearing on any theory of origin of the so-called Nashua Lake deposits. Some of these have been briefly described in two earlier papers,[7] and a more comprehensive study is now under way. These studies have confirmed the work of Crosby and Alden in showing that the deposits were formed in bodies of water occupying the valley, but they have proved also that these bodies of water were relatively narrow marginal lakes surrounding a great mass of ice which occupied the central part of the valley. The present study of the kames and kame terraces confirms this finding, for the kame terraces are without question deposits laid down in narrow bodies of water held between the valley wall and the valley mass of ice, and the rounded hillocks or groups of hillocks represent sandy fillings in embayments or hollows in the mass of ice.

Interpretation of Kames and Kame Terraces

SALISBURY'S INTERPRETATION OF THE NEW JERSEY KAMES

We have in the Massachusetts kames precisely the same sort of structures as those described by Salisbury from the glaciated area of New Jersey:

> "In mountainous regions, where the friction of movement was great, it sometimes happened that considerable masses of ice became stagnant during the dissolution of the ice-sheet. . . . Ultimately some of the valley ice lost its motion, but even after it became stagnant, it exerted an important, though passive, influence in determining the position of stratified drift deposits, and the forms which they assumed."

After explaining how the drainage along the sides of the ice mass would give rise to deposits of stratified drift banked against the ice, he adds:

> "After the ice had melted, these deposits of stratified drift constituted a sort of constructive terrace against the valley slope. . . . A kame terrace, then, is a terrace of sand and gravel, deposited by a glacial stream between valley ice (generally stagnant) and the rock slope of the valley. More or less isolated kames are sometimes associated with kame terraces."[8]

INTERPRETATION OF MASSACHUSETTS KAMES AND KAME TERRACES

The kames and kame terraces of north central Massachusetts differ from those in the New Jersey region only in the greater number of the

[7] T. C. Brown: Report of the Committee on Sedimentation, National Research Council, Bull. 92, 1930, pp. 84-86. Am. Jour. Sci., vol. 19, 1930, pp. 359-367.

[8] R. D. Salisbury: Glacial geology of New Jersey, vol. 5, 1902, pp. 121-123.

kames and the greater areal extent of the terraces. Some of the Massachusetts terraces reach a width of a mile or more, owing to the fact that they were developed in marginal lakes held at constant elevations for considerable periods of time, and not along the valleys of marginal streams. The irregularities of the terrace fronts and of the kame surfaces indicate in part the irregularities of the ice mass against which they were deposited, and in part the changes which took place when the ice melted. The irregular cross-bedding of the lower portions of the exposures indicates that they were laid down against a slowly retreating ice wall. The slumping shown at the valley margin in figure 2, and on either side of the typical kame in figure 5, was caused by the melting away of the ice support and the consequent settling down of the original beds of sand and gravel.

CONCENTRATION OF COBBLESTONES ON KAME SURFACES

Many of the smaller rounded kames of this region show at their summits an accumulation of coarse gravel and cobblestones. This feature is characteristic of kames in other regions and has led to the suggestion that these knob-like hills were formed at the mouths of ice tunnels from which subglacial drainage issued with great force. The coarse material is supposed to have been dropped at the tunnel opening and the finer material carried away by the outflowing water.

The surface covering of coarse material on the kames in this region can be explained in a different way. These kames represent deposits in depressions or embayments in a mass of ice along the margin of a glacial lake. As noted above, the top-set beds in these kame terraces and kames are almost always much coarser than the underlying cross-bedded material. Thus when they were first formed coarse material predominated on the upper surface. Moreover, these sand and gravel deposits were left by the melting ice with slopes which equaled or exceeded the angle of repose for this kind of material, and for a long time they existed probably with little or no covering of vegetation; hence they fell an easy prey to both rain and wind, and a considerable part of the fine material which was originally mixed with this gravel covering was either blown away, washed down to a lower level, or carried to a near-by stream. In other words, the concentration of coarse gravel and cobblestones on the surfaces of these kames seems to be largely a secondary feature due to differential erosion and not wholly a primary feature due to the method of origin.

GRAPHIC ILLUSTRATION OF THE ORIGIN OF KAMES

Two diagrams are here presented to show the conditions which probably brought about the formation of these kame terraces and associated knob-like kames. In the first diagram, figure 8, is shown a portion of a narrow marginal lake, with an ice bay or enlarged crevasse in the side of the ice. The lake was probably well supplied with sediment, a part coming from the surface of the ice mass, but the greater part probably

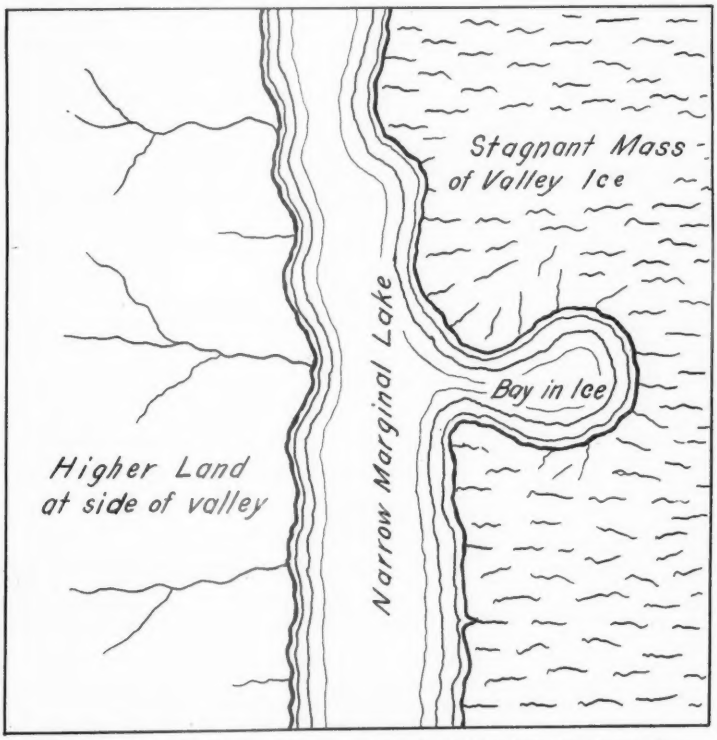

FIGURE 8.—*Map of a Portion of a narrow marginal Lake with a Bay in the Ice* Sand and gravel would fill this bay and, after the ice wall melted, give rise to a typical kame hillock.

contributed by the adjacent land. This material was spread out by the waves and currents of the lake, and any crevasse or embayment in the ice would be filled up at the same time as would the bottom or channel of the lake. Figure 9A shows a section across such a bay or depression in the

ice after it was filled up to the level of the adjacent lake sediments. Eventually when the ice completely withdrew from the valley, the bay-filling would be left without the support of the wall of ice and it would slump down into the form shown in figure 9B. This hillock would then be attacked by erosion and would be slightly modified by the action of rain

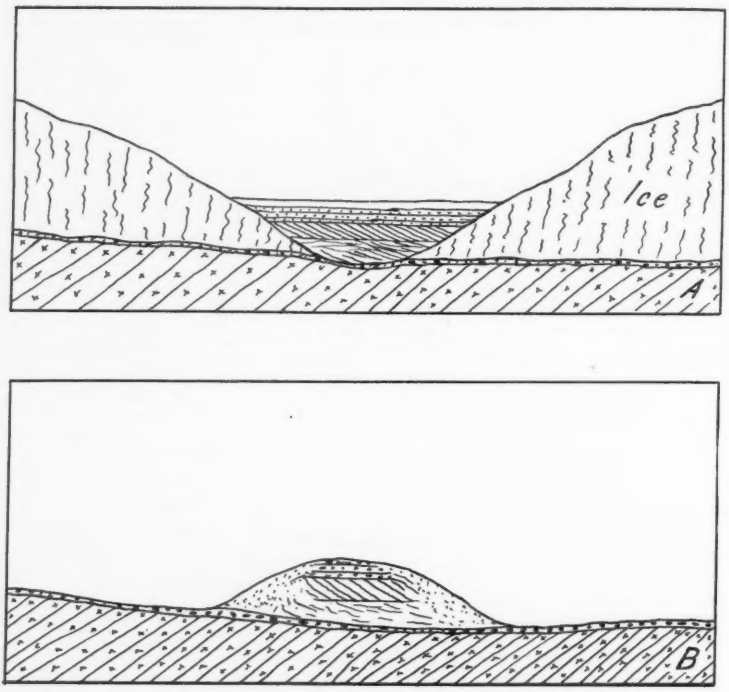

FIGURE 9.—*Section across the ice Bay*

A: Section across the ice bay shown in figure 8 while the ice was still in position.
B: The same section after the ice melted and allowed the sand and gravel to slump into a rounded hillock.

and wind. The chief factor, however, in causing its present form was the ice wall which surrounded it when first formed.

SUMMARY

The sand and gravel plains of central Massachusetts, which have frequently been referred to as delta plains, show the typical internal struc-

ture of kame terraces and differ from them only in areal extent. This greater area is due to the fact that they were developed in marginal lakes held at constant levels for long periods of time. The internal structure of both kames and kame terraces shows that they were formed along the margins of stagnant masses of ice which occupied the valleys.[9] Both the irregularities of the valley margin of the terraces and the knob-and-basin structures of the kames are due to the fact that the sand and gravel deposits were heaped against an irregular ice wall containing many crevasses, pits, and embayments. After the ice wall melted these deposits slumped into positions of repose and then became subject to erosion by rain and wind. Although the surface features have been somewhat modified by erosion, they were largely and primarily determined by the conditions under which they were formed.

[9] See R. F. Flint: Bull. Geol. Soc. Am., vol. 39, 1928, pp. 955-984, for a description of similar terraces in the Connecticut Valley.

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UPPER PALEOZOIC GLACIATIONS OF AUSTRALIA[1]

BY T. W. E. DAVID AND C. A. SÜSSMILCH

(Presented before the Geological Society December 30, 1930)

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[1] Manuscript received by the Secretary of the Society November 24, 1930.

Introduction

In 1919 the authors contributed a paper on the sequence, glaciation and correlation of the Carboniferous rocks of the Hunter River district of New South Wales to the proceedings of the Royal Society of New South Wales (1). In this paper the existence of glacial beds in strata of Carboniferous age in the Hunter River district of New South Wales was described and correlations were suggested with various localities both in Australia and in other parts of the world. The views then put forward have been generally accepted by Australian geologists. Since the publication of that paper, much additional information regarding the Carboniferous and Permo-Carboniferous formations of Australia has become available as a result of the labors of many geologists in the various Australian States, but particularly in Western Australia, Queensland and New South Wales.

In 1928 there appeared in these Proceedings (Geological Society of America) a comprehensive paper by Professor Charles Schuchert (9), perhaps the most important summary of Upper Paleozoic geology since Frech's classical treatise on Die Dyas. In this paper Schuchert presents views of Australian geology so widely divergent from those of Australian geologists generally and, in regard to our Carboniferous glaciation, so utterly at variance with the evidence already given by us, that we should like to restate our evidence with the addition of much important new information which has since become available, both on the Carboniferous and Permo-Carboniferous glaciations of Australia.

The phenomena of the Australian Upper Paleozoic glaciations are of such world-wide interest, and the Carboniferous glaciation is so unique as regards the great development of its tillites, varve shales, etcetera; and has been the subject lately of so much discussion all over the world, that the authors have ventured to submit to the Geological Society of America their views on this subject—views which they believe to be shared by most of their Australian colleagues.

Thesis

The evidence shows that following a widespread development in Australia of marine beds, belonging to Viséan time, and homotaxial, in part at least with the Osage Series of the Mississippian, there came a disconformity ("nonsequence"). This is marked by a Flysch facies of coarse conglomerates, the Wallarobba conglomerates, from 1,000 to 2,000 feet in thickness. (See section 6 on the comparative series of vertical sections in figure 3.) Obviously this conglomerate connotes an extensive emer-

gence of the land. This was followed and accompanied by widespread and prolonged volcanic eruptions, with the tuffs of which are associated some small glacial beds. A Culm flora of *Ulodendron, Stigmaria, Clepsydropsis, Lepidodendron veltheimianum*, etcetera, occurs immediately above this basal Wallarobba conglomerate. Some 3,000 feet higher in this series, glacial conditions had become intensified, and there follow extensive tillites, varve shales, and fluvio-glacial beds, aggregating some 3,000 feet in thickness.

Rhacopteris is specially characteristic of the strata of this terrane, and, in the upper part particularly, by the species commonly known as *Rhacopteris inequilatera* (*Aneimites ovata*), where it is associated with *Cardiopteris* and *Archeocalamites*, and very sparingly with *Lepidodendron veltheimianum*. The age of these glacial beds is probably Upper Culm, or perhaps even newer.

There follows a marked nonsequence, so far as plant life is concerned, a *Glossopteris-Gangamopteris* flora replacing the Rhacopteris flora, and a lithological break is also indicated, but so far no angular unconformity has been observed between the topmost of these strata and the next succeeding beds of the Permo-Carboniferous System (Kamílaroi System of this paper[2]); neither is there evidence of any appreciable thickness of strata having been removed by erosion along the line of junction between these two formations.

The submergence of the land, which ushered in Kamílaroi time, was still accompanied by the deposition of glacial material, the Lochinvar shales, or boulder beds, which end upwards in marine clays. In the 4,000 feet of marine beds which follow, Upper Carboniferous fossil forms, particularly in Western Australia, notably the corals *Mónilopora, Favosites*, and *Syringopora*, the cephalopods *Paralegoceras jacksoni, Paragastrioceras* (?), etcetera, suggest an Upper Carboniferous age for the lower half of this thickness. We hold tentatively that there was a quiet passage from Upper Carboniferous into Lower Permian time about halfway up in this Lower Marine Series, at the Irwin River Coal Basin, Western Australia, and also in the Hunter Basin of New South Wales, and in the Springsure Basin of Queensland. The line of demarcation is tentatively drawn by us at the base of the *Eurydesma cordatum* beds,

[2] The name, Kamílaroi, is taken from that of one of the most important of the former aboriginal peoples of Australia, within whose territory lay the northern coalfield of New South Wales. The Hunter area, which has been taken as the type for the development of the Permo-Carboniferous rocks of Australia, lies in this northern coalfield.

so as to include these latter in the Permian, while the main horizon for *Monilopora nicholsoni* is retained in the Upper Carboniferous.

It will be noted that in the Hunter area of New South Wales the 4,000 feet of Lower Marine Beds are followed by a series of Lower Coal-measures, the Greta Coal-measures of New South Wales, the Collinsville and Mount Devlin Coal-measures of Queensland and the Irwin River Coal-measures of Western Australia. (See Figure 3.) Immediately above these Greta Coal-measures comes another series of marine strata, the Upper Marine Series with two well-marked glacial horizons, that of the Branxton Beds and of the Muree Beds. The Muree horizon marks the last of the glacial deposits of Upper Paleozoic age in Australia as far as at present known. We believe its age to be either Middle or Lower Permian.

Thus in Eastern Australia, the lowest glacial horizon (number 1) is separated by a thickness of strata, inclusive of volcanic rocks, of over 11,000 feet or, if maximum thicknesses be taken, of 15,000 feet, from the newest glacial horizon 5B. Besides, not only is an important series of coal-measures, the Greta Series, intercalated between horizons 4 and 5, but there is a slight break between glacial horizons 1 and 2 and a still more important break between glacial horizons 2 and 3, a paleontological break representing the ending of the newer Culm flora and an early stage of the *Glossopteris-Gangamopteris* flora. In spite of all this evidence, the essentials of which were given in our original paper (1) of 1919, Schuchert, speaking of late Paleozoic glaciations, concludes (9):

> **"It does not appear from the inherent evidence of the tillites of the southern hemisphere that they are all exactly of the same age, or that one or the other is older or younger, but every one concludes that they are of one glacial time, just as various moraines of the Pleistocene belong to one glacial age."**

Surely glacial horizons 1 and 5 (see the following table) of New South Wales are as far removed from one another in geological time as are the Upper Mississippian strata of the United States of America from, say, the Delaware Mountain Series. The great range in geological time of the various late Paleozoic glacial beds of New South Wales in particular is a most essential feature of the whole problem.

It is proposed first to discuss in detail the sequence, evidences of glaciation and geological age of what the authors have already called the Kuttung Series of New South Wales; and this will be followed by a similar discussion of the Kamilaroi System of Australia generally. The latter

Subdivisions of the Carboniferous and Permian Systems of the Hunter River District of New South Wales indicating the various Glacial Horizons.

					Feet	
Permian	Upper Permian	Kamilaroi System	Upper Coal-measures	Newcastle Coal-measures with Upper Permian insects and Labyrinthodonts	1,500	
				Kempsey beds	3,000	
				Tomago (East Maitland) Coal-measures	1,700	
	Middle Permian		Upper Marine Series	Mulbring Marine stage	1,500–3,000	
				Muree stage with marine boulder bed (Bolwarra conglomerate)	400	Fifth Glacial Horizon B
				Branxton stage with abundant erratics in upper part	1,500–3,000	Fifth Glacial Horizon A
	Lower Permian		Lower Coal-measures	Greta Coal-measures (with in places 2,000 feet of interbedded volcanic rocks)	200–2,000	
			Upper part of Lower Marine Series	Farley and Rutherford stages	1,500–2,000	
				Annandale conglomerates with glacial erratics, *Eurydesma cordatum* abundant	about 200	Fourth Glacial Horizon
				Probable slight break here indicated by considerable transgression		
Carboniferous	Upper Carboniferous		Lower part of Lower Marine Series	Lochinvar Marine stage	2,400	
				Lochinvar Glacial beds	300	Third Glacial Horizon
				(Strong paleophytological break here, but no angular unconformity, but a change from marine strata above to fresh-water strata below.)		
	Middle Carboniferous (Upper part of Lower Carboniferous and perhaps lower part of Upper Carboniferous.)		Kuttung Series	Main Glacial stage (with *Rhacopteris* flora)	4,700	Second Glacial Horizon
				Volcanic Stage (with *Lepidodendron*, *Ulodendron* and *Pitys*)	2,500	
				Basal stage: Minor glacial horizon	100	First Glacial Horizon
				Basal stage: Wollarobba conglomerates and tuffs	2,300	
	Lower Carboniferous		Burindi Series	Marine strata with lepidodendron veltheimianum	5,000–10,000	

term embraces all those formations previously included under the term "Permo-Carboniferous" as formerly used by Australian geologists.

In our previous account of the Carboniferous glaciation (1) the Carboniferous strata were divided into two series, the earlier being known as the Burindi Series and the latter as the Kuttung Series. The former does not contain, so far as is at present known, any glacial formations, but it is of importance as giving evidence as to the downward limit of the geological age of the overlying Kuttung Series. It is essentially a marine series containing much volcanic material and with an abundant marine fauna. This fauna is of Viséan age. The true thickness of this series has not yet been determined, but it is not less than 5,000 feet, and is probably in places at least 10,000 feet. It passes upwards into the Kuttung Series without any angular unconformity.

The Kuttung Series

General statement

The Kuttung Series, in all the areas in which it has so far been studied, consists mainly of (*a*) conglomerates (*b*) lavas and tuffs and (*c*) glacial beds (tillites, fluvio-glacial conglomerates and varves); all of these were deposited under terrestrial conditions. The only fossils so far found are those of terrestrial plants, and these taken together, constitute what is known as the "Rhacopteris flora"; this flora will be referred to in detail later. In our original description (1) of these strata from the Seaham-Clarencetown area, the Kuttung Series was subdivided as follows (in descending order):

5. Seaham glacial beds.
4. Paterson rhyolite.
3. Mount Johnson beds.
2. Martins Creek volcanic series.
1. Wollarobba beds.

Since the publication of our first description, the Kuttung Series has been described from a number of other localities by a number of workers, including Dr. G. D. Osborne, Dr. W. R. Browne and Dr. W. N. Benson. All of these workers have obtained similar successions of strata in the different regions which they have investigated. The details from these areas will now be given:

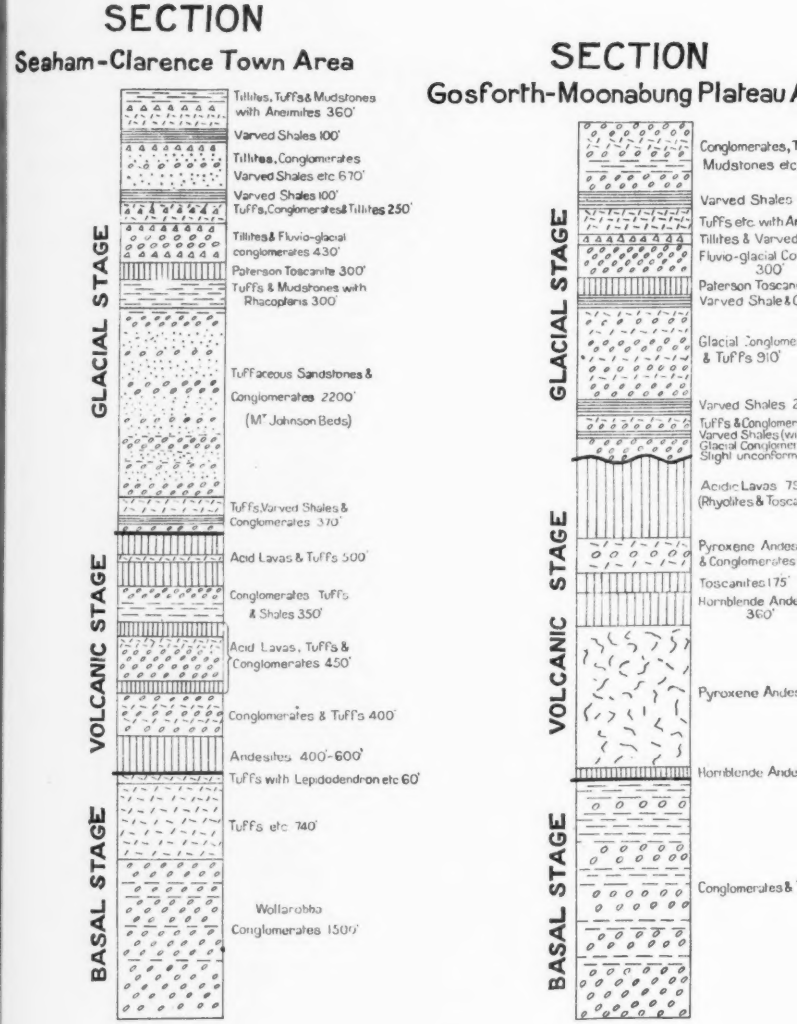


FIGURE 1.—*Sections of the Cutting Series in*

Compiled by C. A. Süssmilch

Plateau Area

onglomerates, Tuffs &
Mudstones etc. 570'

arved Shales 140

ffs etc. with Aneimites 225'

lites & Varved Shales 150'

yvio-glacial Conglomerates
300'

terson Toscanite 300'

rved Shale & Conglomerates 90'

acial Conglomerates
Tuffs 910'

rved Shales 200'

ffs & Conglomerates 200'

rved Shales (with Aneimites) 50'

acial Conglomerates 100-300'

ght unconformity

cidic Lavas 790'

hyolites & Toscanites)

roxene Andesites
Conglomerates 360'

scanites 175'

rnblende Andesites
360'

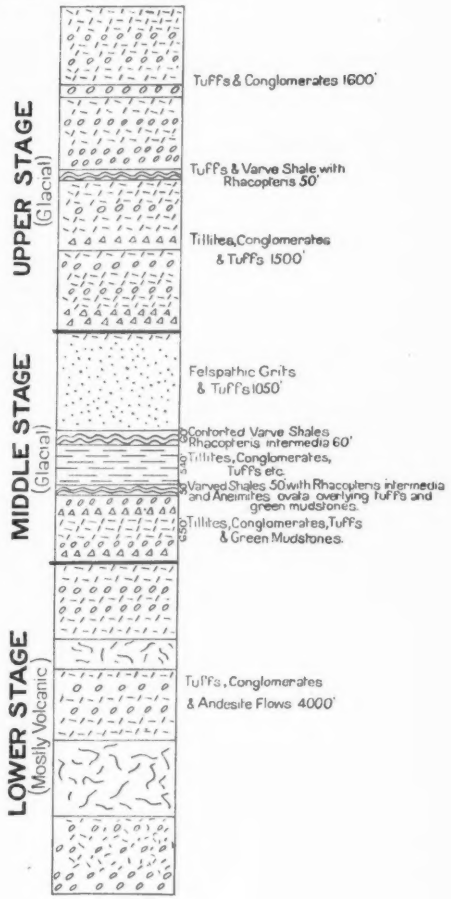
roxene Andesites 1400'

rnblende Andesites 100'

nglomerates & Tuffs 2300'

SECTION

Currabubula District



Series in New South Wales

Süssmilch.

1. SEAHAM CLARENCETOWN AREA

Dr. G. D. Osborne (4) has made a very detailed survey of this area and as a result he has proposed the following subdivision for the Kuttung Series:

		Thickness in feet
III. Glacial stage	Main glacial beds	1,840
	Paterson toscanite (rhyolite)	290
	Lower portion (partly glacial)	2,600
II. Volcanic stage	Lavas, tuffs and conglomerates	2,600
I. Basal stage	Tuffs with pebbles	50
	Tuffs with *Lepidodendron osborni*	10
	Tuffs with conglomerate bands	740
	Conglomerates	1,500
Total		9,630

Osborne has found a glacial horizon below the Paterson rhyolite in what we had previously called the Mount Johnson beds and he has, therefore, grouped together the three topmost subdivisions of our classification under the heading of the "Glacial Stage." The other two subdivisions remain as before, but the local names have been dropped for names of wider application. The following table gives the details of the strata in Osborne's "Glacial Stage" as it occurs in the Seaham area (5).

It will be seen from this section that a glacial horizon occurs near the base of the stage, that is, 1,530 feet below the Paterson toscanite horizon and 1,230 feet below the well-known Paterson fossil plant horizon, from which abundant and well-preserved examples of the Rhacopteris flora have been obtained. Dr. Osborne has also shown that at a place called Abbotsford, about midway between Seaham and Paterson, a *Rhacopteris*-bearing stratum occurs almost at the top of the main glacial beds, that is, just below the base of the Lower Marine Series. He has also found *Rhacopteris*-bearing beds on a similar horizon alongside the Stroud Road near Limeburners Creek here also within a few feet of the base of the Lower Marine Series.

2. GOSFORTH DISTRICT

In 1925 Dr. W. R. Browne (6) published an account of the geology of the Gosforth district, a locality about 20 miles to the west of Seaham; the

SECTION AT SEAHAM

		Thickness in feet
III. Glacial stage (thickness, 4,190 feet)	Mudstones, etcetera	230
	Tillite	50
	Tuffs	80
	Varved shales	100
	Tillite	60
	Tuffs	50
	Fluvio-glacial conglomerates	200
	Mudstones with erratics	100
	Tillites and varved shales	12
	Coarse tuff	70
	Fine-grained sediments	100
	Varve sandstones	80
	Varved shales with local contortions	100
	White sandy sediments with transition into overlying varved shales	100
	Coarse pebbly tuff	50
	Fluvio-glacial conglomerate with local tillites	40
	Tuff	50
	Tillite	10
	Fluvio-glacial conglomerate	420
	Paterson toscanite	100–300
	Tuffs and fine-grained layers containing Rhacopteris flora	300
	Conglomerates	80
	Tuffaceous sandstones	700
	Conglomerates	80
	Tuffs with pebbly bands	370
	Varved shales	40
	Tuffs and breccias	230
	Conglomerates	100
Total		4,100

surface of this area is occupied very largely by the Kuttung Series, of which he gives several detailed sections. The following is that which occurs at Winders Hill in the southern part of the area:

SECTION AT WINDERS HILL—GOSFORTH

Conglomerates
Varved shales

Felsitic breccia
Felsite
Varved shales (with *Aneimites ovata*)
Rhyolite
Felsitic tuffs
Tuffs with plant remains
Varved shales
Fluvio-glacial conglomerates
Green and pebbly felsite tuffs
Varved shales
Fluvio-glacial conglomerates
Pebbly tuffs
Varved shales
Tuffaceous sandstones
Fluvio-glacial conglomerates
Varved-like shales with *Ancimites*
Tuffaceous sandstones
Varved shales with contemporaneous contortions
Tillite

The above strata belong entirely to the glacial stage of the Kuttung Series and total 4,000 feet in thickness. This succession of strata, although it varies in detail, is essentially similar to that already given for the Seaham district, the only important difference being the absence of the Paterson toscanite; this flow has evidently pinched out here. It will be noticed that a number of glacial horizons appear in this section, including seven distinct varved shale horizons; it will also be noticed that fossil plants belonging to the Rhacopteris flora occur at intervals throughout the section, persisting almost to the top.

There can be no doubt of the occurrence here of glacial beds below *Rhacopteris*-bearing strata. This section (since slightly modified in a few details) was published with our original account of the Kuttung glacial beds.

Dr. Browne's paper also gives a detailed description of the Kuttung formation at Hudsons Peak and Mount Drinan, in the northern part of the Gosforth area. His sections, however, do not go to the top of the Kuttung, as these do not occur in this part of his area. Dr. G. D. Osborne, however, has surveyed the adjoining area of the Moonabung Plateau (7) and the following complete section of the Kuttung Series has been taken in its lower part from Dr. Browne's work and its upper part from Dr. Osborne's work:

SECTION FROM GOSFORTH TO THE TOP OF MOONABUNG PLATEAU

		Thickness in feet
III. Glacial stage (thickness, 3,425 feet)	Conglomerates	70
	Purple shales (possibly glacial)	150
	Coarse acid tuffs	100
	Conglomerates	250
	Purple varved rock	140
	Rhacopteris tuffs (number 2 bed)	25
	Acid tuffs	80
	Rhacopteris tuffs (number 1 bed)	30
	Mudstones with plant stems	90
	Varved shales and tillites	150
	Bald Hill conglomerates	300
	Paterson toscanite (upper branch)	100
	Varved shales and conglomerates	90
	Paterson toscanite (lower branch)	150
	Conglomerates, tuffs, etcetera	910
	Varved shales	200
	Tuffs and conglomerates	220
	Varved shales (with *Ancimites*)	70
	Glacial conglomerates (with boulders up to 10 feet in diameter)	100–300
	Slight break here.	
II. Volcanic stage	Rhyolites, toscanites, andesites, etcetera	3,200
I. Basal stage	Tuffs and conglomerates (these contain abundant pebbles of granite and felsite and a few harder rocks showing glacial striæ)	2,300
	Total	8,925

With regard to the glacial stage, this is 3,425 feet in thickness here, and gives a very similar succession of strata to the section at Winders Hill, but the Paterson toscanite which is absent at Winders Hill is present here in a similar position to that which it occupies at Seaham. In the southeastern part of the area, the Paterson toscanite is a single flow as at Seaham, but when followed toward the northwest it is found to split into two branches and between these two branches there are interbedded 90 feet of varved shales and conglomerates. There are also several glacial horizons below the Paterson toscanite. The Rhacopteris flora occurs in strata above the Paterson toscanite as well as below it. In his paper, Dr. Browne has described the occurrence of striated boulders right down

in the Basal Series, that is, in the equivalents of the Wollarobba conglomerates near the base of the Kuttung Series.

3. POKOLBIN DISTRICT

It is many years since this district was first described and no attention was at that time given to the details of the glacial beds. Dr. W. R. Browne informs us that tillite has recently been found on the western side of Mount View on top of the volcanic series and that to the north of Mount Bright and near the extremity of the old Matthews Gap Road, varved shales occur, which are overlain by the Matthews Gap Volcanic Series which in turn are overlain by *Rhacopteris*-bearing tuffs. Dr. Browne has also noted the occurrence at Drakes Hill of fragments of varved shales in the volcanic breccias which occur there and evidently brought up from below; therefore from a lower horizon than some of the *Rhacopteris*-bearing beds.

It is evident from the above that, in this district also, glacial beds occur well down in the Kuttung Series and stratigraphically below *Rhacopteris*-bearing beds.

4. CURRABUBULA DISTRICT

This locality is about 130 miles to the northwest of Gosforth. The Kuttung strata of this region were described by Dr. W. N. Benson and Dr. W. R. Browne in 1920 (2). They give the following details of the succession of strata:

		Feet
Upper portion	Tuffs and conglomerates	1,600
	Rhacopteris tuffs and varved shales	50
	Upper tillites, conglomerates and tuffs	1,500
Middle portion	Rhyolite tuff	50
	Main felspathic grit	1,000
	Tuffs containing *Rhacopteris intermedia* Green mudstones Main varve zone 60 feet thick Tillites and conglomerates Tuffs with *Rhacopteris* and *Aneimites* Conglomerates merging in places into tillites	1,300
Lower portion	Felspathic tuffs and pebble beds with andesite flows ranging up to nearly 1,500 feet in thickness	4,000
Total		9,500

This gives a total thickness of 9,500 feet which compares very well with the 8,925 feet at Gosforth and 9,630 at Seaham. What Benson and

Browne call the lower portion of their section, with its thick andesite flows, may be tentatively correlated with Osborne's basal and volcanic stages, while the middle and upper portions may be tentatively correlated with Osborne's glacial stage. It will be seen that at Currabubula, also, the glacial beds are intimately inter-stratified with strata containing the Rhacopteris flora. A comparison of the Kuttung strata from the various localities is given graphically in figure 1.

5. SUMMARY

From the above descriptions it will be seen that from Seaham to Currabubula, a distance of about 150 miles, the rocks of the Kuttung Series are everywhere similar both with regard to their lithological characters and with regard to the contained fossils. From both points of view, they are absolutely different from the underlying Burindi beds on the one hand, and from the overlying Kamílaroi (Permo-Carboniferous) strata on the other. From all known localities, the strata included in the Kuttung Series are characterized by the occurrence in them of the Rhacopteris flora, particularly so in the upper part of the series. From every locality, also, glacial beds are found to be intimately inter-stratified with *Rhacopteris*-bearing beds, and there can be no doubt that these are contemporaneous and therefore of the same geological age.

Dr. Schuchert, in his endeavor to make the facts fit in with his theory, proposes to move the main glacial beds, that is, all those strata above the Paterson toscanite horizon, out of the Kuttung Series and place them in the Permian system, classifying them as Middle Permian. This divorcing of the upper part of the Kuttung Series from the remainder, is contrary to the facts. The Rhacopteris flora occurs just as abundantly above the Paterson toscanite as it does below it, in fact it ascends to within a few feet of the base of the overlying Lower Marine Series. In his paper Dr. Schuchert went to considerable trouble to prove that the Rhacopteris flora is of a Carboniferous age and on that point all Australian geologists are in agreement with him. No Australian geologist has ever yet claimed anything other than a Carboniferous age for the strata containing this fossil flora. Yet Schuchert himself proposes to shift the Kuttung glacial beds with their Carboniferous fossil plants up into the Middle Permian. In our original description of these glacial beds at Seaham and Paterson, we did not then have undoubted evidence of the occurrence in them of the *Rhacopteris* flora above the Paterson toscanite horizon, but we published in our paper Dr. W. R. Browne's section of the Kuttung beds at Winders Hill, Gosforth; this section showed definitely

the inter-stratification of glacial beds with *Rhacopteris*-bearing beds. Yet in referring to this section, Schuchert writes (page 871) : "It is a foregone conclusion that this species (*Aneimites inequilatera*) can not occur in the Seaham Series." Unfortunately for Dr. Schuchert's argument, it does occur in them. Dr. W. N. Benson's description of the Kuttung Series of the Currabubula district was published in 1920. Dr. G. D. Osborne's detailed description of this series in the Seaham-Clarencetown district, was published in 1922, while his description of the Lambs Valley-Paterson area was published in 1927 and Dr. Browne's description of the Gosforth area was published in 1921, so that the information with regard to all of these areas was available to Dr. Schuchert when he wrote his work. Dr. Schuchert further claims that there is a strong unconformity between the Paterson toscanite and the overlying main glacial beds, and suggests that the break extends from Lower Carboniferous to Middle Permian times. No such unconformity exists. He quotes the presence of boulders of the Paterson toscanite in the immediately overlying glacial bed as evidence of this. If Dr. Schuchert were to inspect some of the lava flows which have been poured out in many parts of the world during the past fifty years, and then imagine what would happen if within a comparatively short period of time a thick sheet of ice were to travel over the surface of such flows, he would undoubtedly realize that boulders of the lava would be picked up and transported by the ice-sheet. This may be seen happening in Antarctica today, in the region of Mount Erebus, etcetera. The Paterson toscanite, where it occurs in the Kuttung Series, is always on the same horizon and always conformable with the overlying glacial beds. At some localities, as has already been pointed out, the Paterson toscanite is absent, and the whole series of Kuttung Strata are still conformable to one another. At Gosforth the Paterson toscanite splits into two flows, and here varves are interbedded between these two flows. The whole of the evidence with regard to the Kuttung Series brings out the following facts:

1. The whole of the strata included by Australian geologists in the Kuttung Series form, with only one slight break, as already shown, a continuous conformable series of Carboniferous age.

2. They were all deposited under terrestrial conditions.

3. Throughout the series, but particularly in the upper half there is an intimate inter-stratification of glacial beds with *Rhacopteris*-bearing beds.

It is therefore obvious that glacial conditions existed in New South Wales in the Carboniferous period, contemporaneously with the existence of the Rhacopteris flora.

6. THE RHACOPTERIS FLORA

Frequent reference has been made to the Rhacopteris flora, an assemblage of fossil plants found occurring in the Kuttung Series. The following is a list of the plants which have been identified:

Equisctales—Archeocalamites
Lycopodiales—Lepidodendron osborni
Ulodendron minus
Stigmaria ficoides
Filicales—Rhacopteris inequilatera (Aneimites ovata)
Rhacopteris intermedia
Rhacopteris römeri
Rhacopteris septentrionalis
Archeopteris (?Rhacopteris) wilkinsoni
Cardiopteris polymorpha
Sphenopteris clarkei
Rhacophyllum diversiforme
Clepsydropsis australis
Coniferales—Pitys süssmilchii

The lycopods and conifers occur mainly in the lower part of the series, although some few specimens of *Lepidodendron* have been found much higher in the series. The ferns on the other hand occur mainly in the glacial stage, extending up into the topmost beds. Of these ferns *Rhacopteris inequilatera* (*Aneimites ovata*) is by far the most abundant. Calamitian stems are also very abundant, occurring throughout the series. With regard to that part of this flora which occurs in the lower part of the Kuttung, Walkom (10) states "the flora of the Kuttung Series is typically Lower Carboniferous, as judged by the standard of European fossil floras"; but speaking of the flora as a whole he states (1): "That it is equivalent to floras which are known from the lower portion of the Westphalian. The horizon of the Kuttung Series would then be that of the Millstone Grit of England, the Ostran-Waldenburg Basin of Silesia, and the upper Pottsville and Lower Kanawha Series of United States of America." We can not therefore exclude the possibility of the Kuttung Series extending into the lower part of Upper Carboniferous time.

Occurrence of glacial Beds of Carboniferous Age in South America

In making a geological comparison of South America with South Africa, Dr. A. L. Du Toit (8) has given particular attention to the glacial

beds of Upper Paleozoic ages and has described a series of glacial beds of Carboniferous age for the district of San Juan in the Argentine Republic. Here to the south of the town of San Juan there occurs a series of fresh-water strata called the Paganzo Series, previously described by Stappenbech, Bodenbenden and Keidel, and this series contains glacial beds. From one locality in the Sierra Chica de Zonda to the south of San Juan, Dr. Du Toit records the following section (in descending order):

	Thickness in meters
Sandstone and shales	
Greenish shales	
Third glacial zone	12
Greenish shaly beds Pebbly grits and sandstones	50
Second glacial zone (with boulders up to 3 meters in diameter)	50
Yellowish gray sandstones Carbonaceous shales, mudstones, flagstones and thin sandstones with fossil plants (*Rhacopteris* and *Cardiopteris*)	145
First glacial zone	8–10

These strata rest unconformably on Ordovician limestones and shales, the limestones showing glacial striæ. With regard to this section Du Toit writes as follows:

"The Gondwana embraces three distinct glacial horizons, one of which forms the very base of the system, while the intercalated sediments between that and the second glacial horizon yielded plant remains, among which were the Carboniferous genera *Cardiopteris* and *Rhacopteris*."

In speaking of the occurrence of the Paganzo Series in the district generally Du Toit refers to the close association in these strata (a conformable series) of the Rhacopteris flora with the Glossopteris flora and refers to this matter in these words:

"The outstanding feature of the sections just described is the direct evidence they furnish on the position of the plant-bearing horizon in relation to the glacials, at the same time proving the close association of the European Carboniferous plant forms with members of the *Glassopteris* flora."

Du Toit indicates the possibility of the two floras actually occurring in the same beds, although he thinks this doubtful, but he seems to be quite certain that strata containing representatives of the two floras are so closely associated that there is no important time break between them.

In Argentina also Du Toit records the association of glacial beds with marine strata of Carboniferous age; from Barreal in the Quibrada del

Salto, 45 kilometers to the north of the Sierra Chica de Zonda he records the occurrence of a bed of tillite, more than 25 meters in thickness, passing upwards by degrees through sandy mudstones into shales containing an abundance of marine fossils including *Spirifer, Productus, Pseudamusium, Spiriferina, Polyzoa* and *Fenestellidæ*. The fossil forms obtained have been described by Dr. Cowper Reed (8), who arrives at the important decision that this Barreal marine fauna is of undoubted Carboniferous age, belonging probably to the base of the Upper Carboniferous.

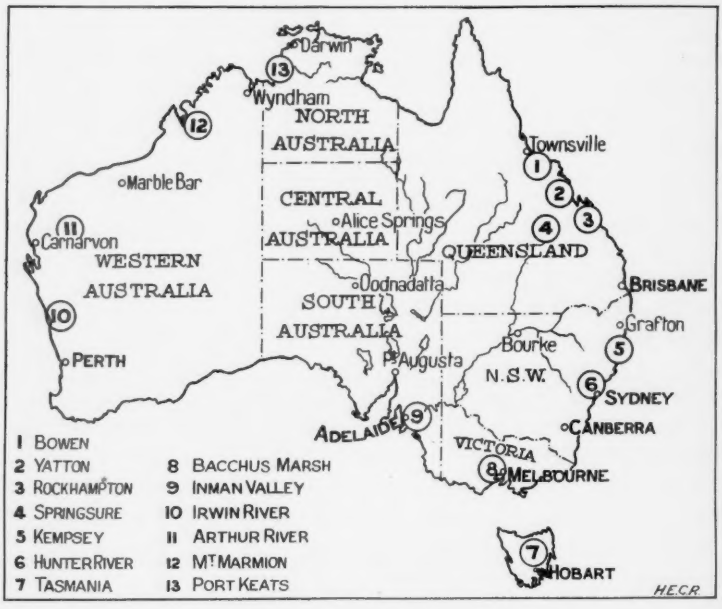


FIGURE 2.—*Map showing Localities referred to in Figure 3*

We have therefore in Argentina glacial beds associated with both marine and fresh-water beds of undoubted Carboniferous age. The evidence of this interesting analogue strikingly confirms that already supplied by Australia, both as regards the contemporaneity of the Rhacopteris flora with a widespread ice age and also in reference to the close juxtaposition, without any noticeable break in the sequence, of the topmost glacial beds of the newer (?) Culm flora with the basal glacial beds of the so called Permo-Carboniferous system.

⑬
PORT KEATS
(North Australia)
⑫
MT MARMION
MT WYNNE
MT PIERRE
(Western Australia)
⑪
ARTHUR RIV.
(Western Australia)
⑩
IRWIN RIV.
(Western Australia)
about 440 miles
about 730 miles
about 330 miles
about 1440
Cainozoic on Trias with Estheria
Upper Marine Series ⊗
Black shales with Glossopteris & Noeggerathiopsis
Sandstones & Mudstones with Aviculopecten Carbonaceous shale with thin laminae of Coal (Greta) and Calamites, possibly the Fossil plant horizon of Yarrada Hill.
HORIZON OF
Jurassic sandstones with Otozamites.
⊗ These Coal measures are with a total of 21 Feet of
Glossopteris Gangamopteri
Sphenophyllum, Noeggerathiop
Irwin River Coal Measures ⊗
Sandstones with Chonetes prath, Mon
Limestone with Parallelocerus
Buff beds 600 Feet
Grey shales about 500 Feet
Tillite, 200 Feet, Erratics up to 60
Grey to green argillaceous li
Proterozoic shales limeston
conglomerate
Archaen schists gne
Upper Marine Series
Lower Marine Series (Upper Div.)
Lower Marine Series (Lower Div.)
Geikie & Rough Range Series
Napier Range Series
Kimberley Series
7
6
5
4A
2
1
X
Favosites marmionensis Monticulipora Hudsoni
Cladochonus tenuicollis
Lyons Conglomerate glacial beds
Slight unconformity
Massive limestones and Calcareous Flaggy sandstones with traces of mineral oil
Lithostrotion (Lithodendron) affine Syringopora, Rhynchonella pleurodon
Unconformity
Limestones with Stromatoporella, Brancoceras, (?) cf. rotatorius etc
Schists and gneissic granite
Marine sandstones about 300 Feet thick
Limestone about 300 Feet thick & limestone conglomerate 50 Feet ※
Lyons Conglomerate glacial 50 Feet
Sandy and Flaggy limestones
The Following Fossils have been recorded:-
Dybowskiella geei, Nubecularia, Polypora smithii
Fenestella bicellulata, F. plebeia, Ramipora sp. cf. Parmin
Carbf. of the Arctic, Rhombopora hindei, Streblotrypa browni
※ This limestone has yielded Exechinopora (Hexagonella) crucialis, Rhombopora tenuis, Athyris macleayana, Autosteges, barracoodensis & Dielasma spine. Symphysial teeth of a large shark either Helicoprion davisii or Toxoprian davisii have been found here in a loose concretion in the bed of the Arthur River. This Fossil would probably have the greatest stratigraphical value of any Fossil ever discovered in Australia, were it in situ.

INDEX TO G

13	**JURASSIC** White and reddish sandstones with Otozamites	10	**LOWER TRIAS** Narrabeen Beds
12	**UPPER TRIAS** Wianamatta Shales	9	**UPPER PERMIAN** Upper Coal-measures Newcastle & Tomago Stages N.S.W. Upper Bowen Series Q. Upper & middle Collie Coal-measures W.A.
11	**MIDDLE TRIAS** Hawkesbury Sandstone	8	**UPPER PERMIAN** Upper Coal-measures. Tomago Series.

Comparative series of vertical sections of Permian and

(Compiled by T.W.Edgeworth David)

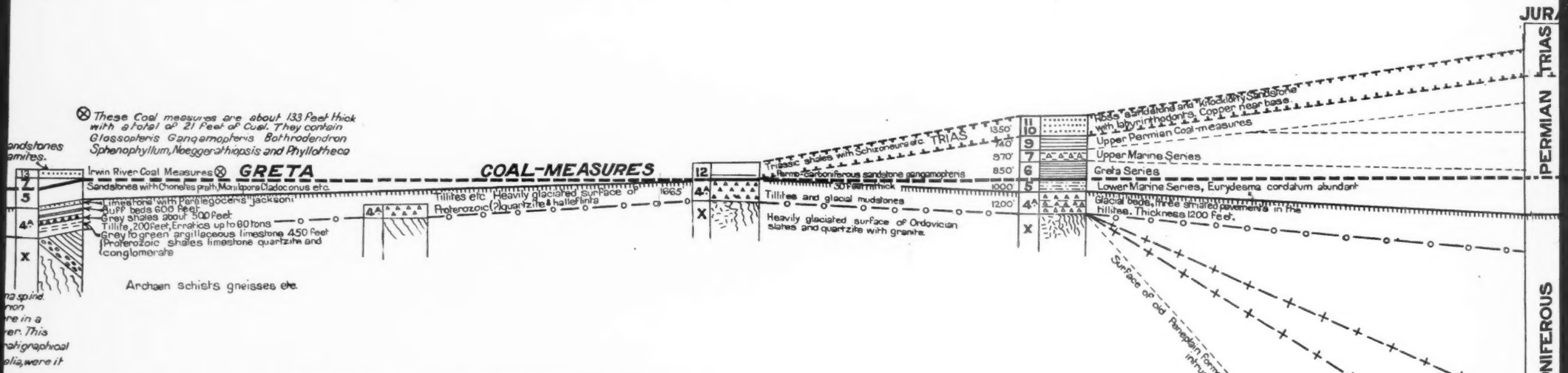
⑩ **RWIN RIV.** (Western Australia)

INMAN VALLEY ⑨ (South Australia)

BACCHUS MARSH ⑧ (Victoria)

TASMANIA ⑦

about 1440 miles — about 360 miles — about 315 miles — about 675


⊗ These Coal measures are about 133 Feet thick with a total of 21 Feet of Coal. They contain Glossopteris Gangamopteris Bothrodendron Sphenophyllum, Noeggerathiopsis and Phyllotheca
Irwin River Coal Measures ⊗ GRETA COAL-MEASURES
Sandstones with Chonetes prath, Monticulipora Cladoconus etc.
Limestone with Parallelodon jacksoni
Tuff beds 600 Feet
Grey shales about 300 Feet
Tillite, 200 Feet, Erratics up to 80 tons
Grey to green argillaceous limestone 450 Feet
Proterozoic shales limestone quartzite and conglomerate
Archaen schists gneisses etc.
Tillites etc. Heavily glaciated surface of Proterozoic (?) quartzite & halleflints
1965
Triassic shales with Schizoneura etc. TRIAS 1350'
Permo-Carboniferous sandstone gangamopteris 740'
30 Feet thick 850'
Tillites and glacial mudstones 1000'
Heavily glaciated surface of Ordovician slates and quartzite with granite.
1200'
Rolled sandstone and Woodbine Sandstone with labyrinthodonts, Copper near base
Upper Permian Coal-measures 970'
Upper Marine Series
Greta Series
Lower Marine Series, Eurydesma cordatum abundant
Glacial beds, three striated pavements in the tillites. Thickness 1200 Feet.
Surface of old Peneplain formed of Cambro-Ordovician rocks & intrusive granites
JURA
TRIAS
PERMIAN
CARBONIFEROUS
DEVONIAN

INDEX TO GEOLOGICAL FORMATIONS

ER PERMIAN
s Newcastle & Tomago Stages N.S.W.
s Q. Upper & middle Collie Coal-measures W.A.

ERMIAN
ures. Tomago Series.

7 — **LOWER(?) PERMIAN**
Upper Marine Series
Middle Bowen Series Queensland

6 — **LOWER PERMIAN**
Greta Coal-measures N.S.W. Collinsville Coal-measures Q.
Bruni Coal-measures T., Irwin River Coal-measures W.A.
Lower Collie Coal-measures W.A.

5 — **LOWER PERMIAN**
Lower Marine Series with Garretts Coal Seam N.S.W.
Mt Devlin Coal-measures of Queensland

4A — **UPPER CARBONIFEROUS(?)**
Lower part of Lower Marine Series N.S.W. (Lower Bowen Queensland) Mt Britton Yatton Cracow Texas Drake Kempsey Maria Id. The extensive marine series of Western Australia below the horizon of the Irwin River Coal-measures. Glacial beds at the base of the Kamilaroi System e.g. Lochinvar glacials N.S.W., Kempsey glacials N.S.W., Derrinal & Bacchus Marsh Vic. Wynyard Tas., Inman Valley S.A. Lyons Conglomerate W.A.

4 — **UPPER CARBONIFEROUS(?)**
Dinner Creek Series Qld., with oldest Glossopteris Flora including Sphenophyllum

3 — **MIDDLE CARBONIFEROUS**
Kuttung Series Freshwater N.S.W., Hunter, Currabubula and Kempsey Districts. Anaimites beds of Drummond Range and Newellton Q., Marine Neerkool Series Q.

2 — **LOWER CARBONIFEROUS**
Burindi Series N.S.W.
Rockhampton Series Queensland

1 — **UPPER DEVONIAN**
Quartzites hard shales etc. with Lepidodendron australe.

X — **PRE-DEVONIAN**

FIGURE 3.—*Comparative Series of vertical Sec in Australia an*

ermian and Carboniferous rocks . Australia and Tasmania.

iled by T.W.Edgeworth David)

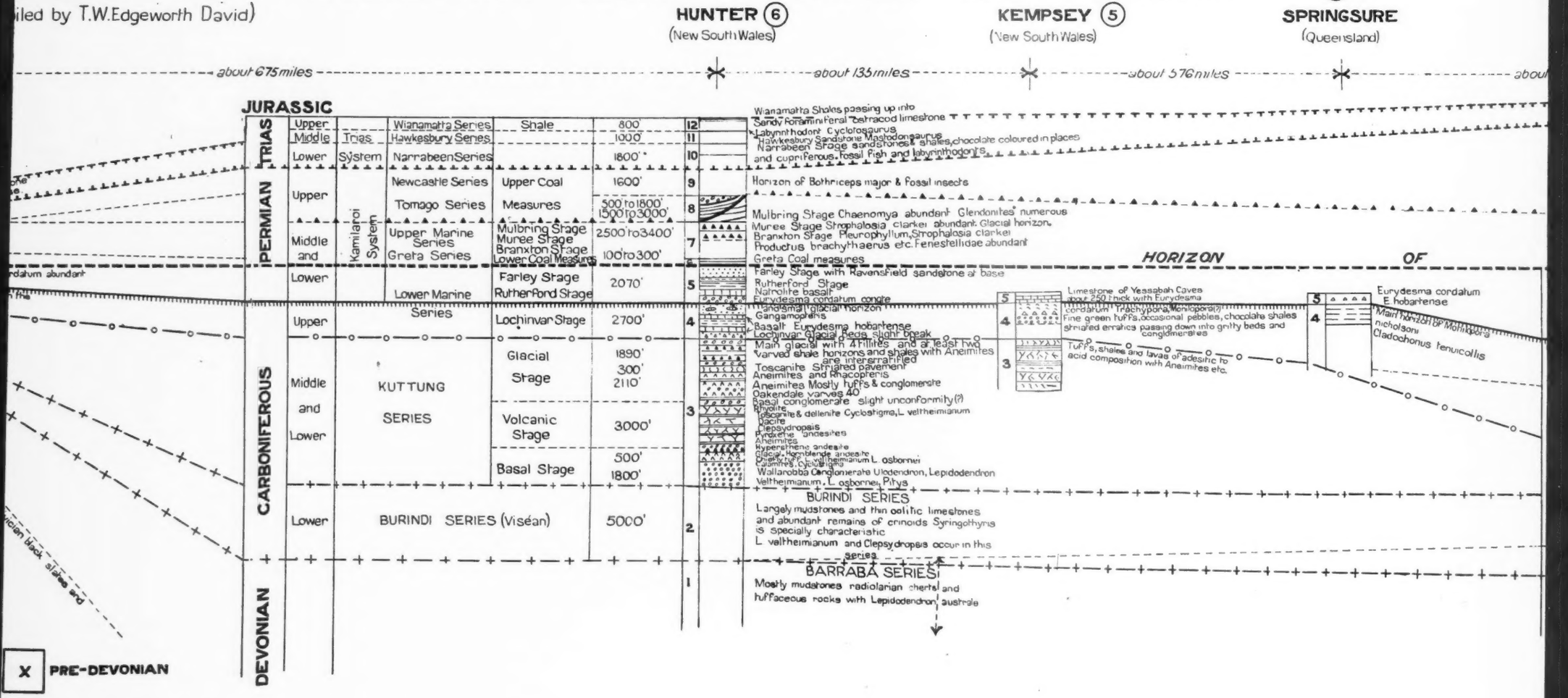


FIGURE 3.—*Comparative Series of vertical Sections of Permian and Carboniferous Rocks in Australia and Tasmania*

and Tasmania.

KEMPSEY ⑤ (New South Wales)

about 576 miles

④ **SPRINGSURE** (Queensland)

about 180 miles

③ **ROCKHAMPTON** (Queensland)

about 150 miles

② **YATTON** (Queensland)

MtBRITTON

about 200 miles

① **BOWEN** (Queensland)

Upper Bowen Freshwater Beds 9600 Ft.

Middle Bowen Marine Beds 2400 Ft.

Coals 700 Ft.
Volcanics 2000 Ft.
Coals 400 Ft.
Volcanics 3000 Ft.

TRIASSIC SERIES — TRIAS

UPPER PERMIAN

Sandstones and shales largely tuffaceous with some interbedded lava sheets

Coals & shales of Sandy Creek, Blair Athol (?)
Fossil wood in tuff

Mainly tuffaceous beds

Marine horizon with Derbya (?)

Coal of Dawson Blenheim, Coal Gully etc.
Glossopteris shales
Deintree Coal Seam
Glacial erratics
Derbya Zone
Eurydesma zone (S. clarkei) 33 Ft. thick
Glacial erratics

LOWER PERMIAN

Collinsville Coal-measures Coal 45-60 Feet
Rhyolitic tuffs pitchstone shales etc.
Mainly zeolite basalts and andesites tuffs and agglomerates

Mt Devlin Coal-measures with Glossopteris

Mt Toussaint Volcanic Series
Andesite tuffs and agglomerates and sheets with thin beds of sandstone.

UPPER CARBS.

Pre-Devonian Schists and granite

HORIZON OF GRETA COAL-MEASURES

PERMIAN

CARBONIFEROUS

DEVONIAN

Lower
Upper
Middle
Lower (Visean)
Tournaisian

Middle Bowen Series — Lower Div.
Lower Bowen Series — Upper Div.
Lower Bowen Series — Lower Div.
Dinner Creek Series
Neerkol Series
Rockhampton Series

Limestone of Yessabah Caves
about 250 Feet thick with Eurydesma cordatum, Trachypora, Monticulipora(?)
Fine green tuffs, occasional pebbles, chocolate shales striated erratics passing down into gritty beds and conglomerates
Tuffs, shales and lavas of andesitic to acid composition with Aneimites etc.

Eurydesma cordatum
E. hobartense
Main horizon of Monticulipora nicholsoni
Cladochonus tenuicollis

Horizon of Collinsville Coal Measures
Eurydesma cordatum, Cladochonus tenuicollis, Monticulipora nicholsoni, Trachypora wilkinsoni

Horizon of Mt Devlin Coal Measures
Porphyrites and Agglomerates
Freshwater sediments with Fine-veined Glossopteris, Gangamopteris and Spenophyllum in a series of andesitic lavas and tuffs with carbonaceous shale and basal conglomerate
Mostly grits, sandstones and conglomerates with interbedded andesites. Fossils Pustula Productus cf scabriculus, Spirifer mosquensis etc
Hexagonella crucialis Lion Creek Oolitic Limestone
Amygdalophyllum, Lithostrotion, Archimedes etc. Grits, tuffs and interbedded andesites
Laminated black cherts with Protocanites pianorbiformis
Pseudanetites ammonitoformis Pseudanetites dubius
Sandstones etc. with Lepidodendron australe passing down into limestones with middle Devonian Fauna

Big Strophalosia bed
Paragastrioceras(?) Taeniothaerus
Rhyolites
Glossopteris shales
Andesites
Black shales
Andesites
Glossopteris
Anidanthus

Chocolate coloured in places
Glendonites numerous
Glacial horizon
S. clarkei
Eurydesma abundant

The Kamílaroi System

GENERAL STATEMENT

It is now proposed to discuss the sequence and glacial evidences of what we term the Kamílaroi System which is equivalent to the "Permo-Carboniferous," as formerly used by Australian geologists.

In order to try and clarify some of the obscure problems of these Kamílaroi strata a comparative series of vertical sections from various localities in Australia has been prepared and numbered 1 to 13 in figure 3.

These may now be discussed in moderate detail, in regard to their salient features. It will be observed that, for purposes of correlation, the horizon of the Greta Coal-measures, as being remarkably persistent over great areas, has been taken as a datum, to which all strata of Kamílaroi age are referred. The sequence, which occurs in the type district of the lower Hunter, may be considered first in ascending order.

A. HUNTER RIVER DISTRICT, NEW SOUTH WALES

(See section 6, figure 3)

The Kamílaroi system begins with some reddish-brown to claret-colored shales with numerous small erratics, many of which are well striated. These are known as the Lochinvar glacial beds and are 300 feet in thickness.

The ice-sheets responsible for this glacial deposit must have come down close to sealevel in early Kamílaroi (probably late Upper Carboniferous time), for at the top of these glacial shales are found a few of the marine pelecypod *Eurydesma hobartense*. This is a small and thin-shelled variety. A nonsequence must certainly occur, both lithological and paleontological, at the base of these Lochinvar beds, but nevertheless, there is no angular unconformity, and apparently no evidence of contemporaneous erosion, nor of any considerable thickness of beds being missing between the top of the Kuttung and the base of the Lower Marine Series. It looks as though there had been a slow and prolonged subsidence of the Kuttung land areas, eventually admitting the Pacific over the foothills of the Kuttung highlands, but the glacial conditions persisted for a very considerable time longer on the highlands to the south and west of the Hunter area, as glacial strata occur at intervals throughout the Lower and Middle Permian formation.

The terrane, which had been supplying the boulders to the Kuttung, appears to have been now submerged, or at all events to have been no longer available as a source of supply of the material forming the errat-

ics. In place of the dominant granites, aplites and quartz-porphyries of the Kuttung glacial beds, it is found that diorites, gabbros and porphyrites are more characteristic of the Lochinvar glacial beds, and some of the quartzite erratics with *Spirifer disjunctus* were evidently transported from the direction of Rydal and Bathurst, about 100 miles to the south-west of Lochinvar. This remark also applies to the three younger glacial horizons to be described later. Immediately overlying the *Eurydesma hobartense* bed there is about 300 feet of sandstone containing an admixture of plants and marine fossils. The plants are indeterminable; the marine fossils comprise a *Spirifer* of the *striatus* group, a *Dielasma* of a new species, a *Conularia,* probably of a new species, and a *Platyschisma.*

At Lochinvar at about 1,200 feet above the Lochinvar glacial beds (or 550 feet, if the thickness of an interbedded sheet of basalt be omitted) there is an assemblage of fossils which is of Kamílaroi type, with the exception of a *Seminula* allied to a Burindi (Viséan) type, and a small transitional type of *Spirifer aff. tasmaniensis.*

W. R. Browne and W. S. Dun (11) give the following list of fossils from a bed of limestone about 500 feet stratigraphically (the thickness of an intercalated flow of lava being omitted) above the top of the Lochinvar glacial beds:

"Crinoid stems and ossicles, *Fenestella internata, F. fossula,* F. sp., *Seminula* sp. nov., *Martiniopsis subradiata, Spirifer aff. tasmaniensis* (a small type probably transitional), *Deltopecten limaeformis, Aviculopecten englehardti, A. tenuicollis, A. mitchelli, Chaenomya* sp., *Conocardium* sp. nov., *Maconia* sp. nov., *Orthoceras* sp."

They comment:

"A departure from a normal Permo-Carboniferous facies is afforded by the specimen probably referable to *Seminula.* A possible relationship with the Burindi fauna is evidenced by this latter, and by the *Spirifer,* which may be regarded as a distinctly transitional type. In all other respects the fauna may be looked upon as definitely Permo-Carboniferous."

Little is known of fossils in the considerable thickness, about 600 feet, of strata, largely tuffaceous mudstones, which intervene between the top of the above limestone and the next known fossiliferous horizon, the shaly mudstones with *Gangamopteris* and *Ptychomphalina,* south of Lochinvar railway station. This is the lowest horizon to which *Gangamopteris* has as yet been traced in New South Wales, and, for reasons to be adduced presently, is considered by us to be probably of Upper Carboniferous age.

Above this horizon are mudstones about 600 feet thick becoming very tuffaceous and passing upwards into greenish calcareous and tuffaceous clayey sandstones rich in marine fossils. This is the Harpers Hill horizon. Associated with it is a minor glacial horizon. The tumultuous bedding of the boulders, many of them with their principal axes at right angles to the planes of bedding, and the faint striations, suggests the action of ice floes rather than of glacier ice.

Eurydesma cordatum is specially characteristic of this horizon. This fossil a few feet higher in the series forms a regular "oyster-bank" type of deposit, occurring in vast numbers in among the boulders of the conglomerate, its shell, of great thickness near the umbo, enabling it to withstand the buffeting of the waves along a shore line. A short distance above this horizon, which will be called the main *Eurydesma cordatum* horizon and which is considered to be the basal bed of the Permian, casts of *Productus brachythaerus, Strophalosia clarkei,* and *Protoretepora ampla* become very numerous, and are surely indicative of a Permian age. The importance of this main *Eurydesma cordatum* horizon, as probably lying at the base of the Permian, and so dividing the Permian from the Upper Carboniferous can now be explained. It can certainly be identified with a similar horizon in Queensland at Silverwood near Warwick, and at Springsure, and probably still farther north at Cracow, Tooloomba and Yatton.

At all these localities two corals, assumed to be of Upper Carboniferous age (their range is usually Devonian to Carboniferous, mostly Lower Carboniferous), are specially characteristic, namely, *Monilopora nicholsoni* and *Cladochonus tenuicollis.* Associated with these is the large productid shell *Taeiothaerus,* gen. nov., formerly *Productus subquadratus,* but now considered to be distinct from it. These three forms are also very characteristic of the marine beds of Western Australia, which there underlie, apparently with some slight unconformity, the horzion of the Irwin River Coal-measures. These last are probably the equivalent of the Greta Coal-measures of New South Wales. In Western Australia *Monilopora nicholsoni* is associated with a dendroid *Favosites, Favosites marmionensis,* in the so-called Permo-Carboniferous rocks of the Kimberley region.

The main *Eurydesma cordatum* horizon is also represented at Maria Island in Tasmania where it is above the horizon of the Wynyard glacial beds to be described presently.

If now the sequence of the Kamílaroi system of the Hunter area be followed upwards from the main *Eurydesma cordatum* zone, marine strata

1,800 feet in thickness separate this horizon from that of the Greta Coal-measures. It may be noted that, at a horizon 1,000 feet below the base of the Greta Coal-measures, the Ravensfield sandstone is particularly rich in a fossil formerly classed as *Agathiceras micromphalum,* but now considered to be a *Bellerophon.*

In addition to the normal *Glossopteris-Gangamopteris* flora with *Noeggerathiopsis,* the Greta Coal-measures contain *Sphenophyllum,* a plant which is not known to ascend any higher. In places no less than about 2,000 feet of basic lava agglomerate and tuff are intercalated in the Greta Coal-measures increasing its normal thickness of from 100 to 300 feet to over 2,000 feet.

The coals are of a sapropelic character and devoid of fossil wood. There appears to be a slight break indicated by coarse conglomerates, both at the base and at the top of these coal-measures, as well as by the prolonged volcanic eruptions, the products of which are interstratified in the Greta Coal-measures.

The overlying Upper Marine Series, from 4,000 to over 6,000 feet thick, have two glacial horizons, namely, the Branxton glacial horizon about 1,500 feet above the Greta coal, and the Bolwarra conglomerate in the Muree stage about 2,000 feet above the Greta Coal-measures.

These glacial beds consist of large boulders, up to a cubic meter in size, some of which exhibit glacial striæ. The Bolwarra conglomerate in places, by reason of the number of the erratics, almost passes into a marine boulder clay. The parent rocks of these boulders occur in areas like those of Rydal and Bathurst over 100 miles to the southwest of West Maitland. It may be added that the only specimen of an *Agathiceras* found in Australia and showing a suture, and referred by Etheridge to *Agathiceras micromphalum,* was obtained from a shaft sunk in the Upper Marine Series, at a horizon a few hundred feet above the top of the Greta Coal-measures. Dr. F. W. Whitehouse questions even this specimen being an *Agathiceras,* and considers it nearer to a *Paralegoceras.*

Above the Bolwarra conglomerates are the Muree beds with a wonderful zone of *Strophalosia clarkei,* with the substance of the shell preserved. This zone can be identified in the Bowen Coalfield of Queensland, over 800 miles to the north.

Reference to the vertical section taken in the Hunter area shows that at the top of the Upper Marine Series between it and the base of the Upper Coal-measures there is in places a marked break. We believe that this break, due to orogenic disturbances, and accompanied in the southern

or Illawarra coalfields of New South Wales by much volcanic activity, occurred about Middle Permian time, corresponding approximately to the epoch of Saalian folding, as described by Stille (12).

In the Maitland area of the Hunter Valley the strata from the top of the Upper Marine downward became so domed in places and denuded that the Triassic rocks come to rest directly on the Bolwarra conglomerate of the Muree beds. In this case some 2,000 feet of the shales of the Mulbring stage (forming the top of the Upper Marine Series) and at least an equal thickness of fresh-water coal-measures—an aggregate of at least 4,000 feet—are cut out through the unconformity. It may be noted that in the lower stage of these Upper Coal-measures, the Tomago Series, coniferous trees, *Dadoxylon* mostly, attain a diameter of a foot or upward, while in the Upper stage, that of the Newcastle Series, these trees reach dimensions of about 3 feet through at the butt, and about 120 feet high. On several horizons of the Upper Newcastle Series there are fossil forests.

This obviously indicates an amelioration of the climate in Upper Permian time. That it was Upper Permian is proved both by the fossil insects and labyrinthodonts. These amphibians are *Bothriceps australis,* and *B. major.*

The exact horizon of *Bothriceps australis* is not known, but *Bothriceps major,* somewhat imperfectly preserved, occurs in "kerosene shale" (torbanite) at the Airly Mine in the Upper Division of the Newcastle Coal-measures in the Blue Mountains west of Sydney.

Writing to one of the authors, Professor D. M. S. Watson states:

> "It is clear that Sir Arthur Smith Woodward's reference of this specimen to *Bothriceps* is essentially correct. It belongs to the family *Brachiopidæ* of the Stereospondylous *Labyrinthodontia,* or to the Rachitomous family of *Dvinosauridæ,* which includes their ancestors. . . . The *Dvinosauridæ* include a single genus from the Upper Zechstein of the Dvina in North Russia. . . . The next member of the group known is the single specimen of *Brachyops laticeps,* from the Damuda of India, the age of which can not be fixed with any accuracy. . . . In the fact, which is clear from the specimen, that the occiput is sloping, it (*B. major*) differs from the Permian form, and resembles *Brachyops* and *Bothriceps australis,* which, from their clearly more primitive structure, must be earlier than the Lower Triassic *Batrachosuchus.* Thus it is most probable that the age of *Bothriceps major* is nearly on the division between the Permian and the Trias."

Fortunately this amphibian occurs close to what, on the evidence of the plants and insects, would have been taken to be the dividing line between the Upper Permian and the Trias.

It may be added, as further evidence of the break between the Upper Marine Series and the Upper Coal-measures, that at the dividing line between the upper and lower divisions of the Newcastle Series there are numerous pebbles of Greta coal, as described by one of us (13). These pebbles of coal, so hard when imbedded in the conglomerate that they were not in the least deformed by the superincumbent pressures, show that the folding of Pre-Newcastle (Pre-Upper Permian) time had already become so accentuated that denudation had removed perhaps 4,000 feet of strata so as to expose the Greta Coal-measures to erosion before the deposition of the strata of the Newcastle Series was completed.

B. KEMPSEY DISTRICT, NEW SOUTH WALES

(See section 5, figure 3)

From this type section of the Hunter one may pass on to the next section, namely, that of Kempsey. At the top of the section is a limestone bed about 250 feet thick, with *Eurydesma cordatum*. *Monilopora* is thought to occur there, and at about 300 feet below the base of the limestone are glacial beds, probably on the horizon of the Lochinvar glacials (the third glacial horizon), but possibly on the fourth horizon. The absence of *Monilopora* farther south was probably due to a climatological barrier.

C. SPRINGSURE DISTRICT, QUEENSLAND

(See section 4, figure 3)

Next is the section at Springsure, Queensland. This section is of special importance in showing that *Glossopteris* descends far into the Lower Marine Series, probaby into rocks of Upper Carboniferous age. The section just completed by J. H. Reid is as follows:

Feet	
5,000	Upper Bowen Coal-measures with much fossil wood like that in the Newcastle Coal-measures of New South Wales.
900	Middle Bowen (=Upper Marine Series of New South Wales). Glacial erratics at base = glacial horizon 5.
700	*Conularia sandstones* Coal with *Gangamopteris* and *Glossopteris*
500	Marine sandstones
300?	Dilly stage of Lower Marine Series Numerous large erratics in Lower Marine Series on this horizon of *Eurydesma cordatum* associated with *E. hobartense*. This is probably glacial horizon 4.
1,000	Sandstones and shales, at base of Permian Chief horizon of *Trachypora wilkinsoni* and *Monilopora nicholsoni* marking the top of the Upper Carboniferous.

Feet	
2,500	Aldebaran sandstones with thin coal-measures carrying *Glossopteris*
350	Gypseous stage. Abundant plants: *Productus brachythaerus; Martiniopsis subradiata*, small form; *Deltopecten comptus.*
950	Staircase sandstones.

D. ROCKHAMPTON DISTRICT, QUEENSLAND

(See section 3, figure 3)

The next section is at Rockhampton in Queensland and is again due to the recent work of J. H. Reid, and supplies several important new data.

The section in descending order commences with some 5,000 feet in thickness of porphyrites and agglomerates. The horizon of *Eurydesma cordatum* is considered to be halfway down in this series, which is known as the Lower Bowen Series. The main horizon for *Monilopora nicholsoni,* if marine beds were developed in this region, would be a few hundred feet lower than the above horizon. Accordingly the dividing line between Permian and Carboniferous has been drawn about halfway down in this series. Next below this volcanic series is a fresh-water series, the Dinner Creek Series, with interstratified andesitic lavas and tuffs. This series contains an undescribed new type of fine-veined *Glossopteris,* also *Gangamopteris* and *Sphenophyllum* associated with carbonaceous shales. Reid stresses the point that this horizon for *Glossopteris* is older even than that at Springsure, and is certainly of Upper Carboniferous age. The Dinner Creek Series is separated by a strongly marked basal conglomerate from the underlying Neerkol Series. The Neerkol Series is for the most part marine. It consists chiefly of grits, sandstones and conglomerates with interbedded andesites. It has yielded *Pustula, Productus* cf. *scabriculus, Spirifer mosquensis,* etcetera.

Dr. F. W. Whitehouse regards this as a possible marine equivalent of the fresh-water Kuttung Series of New South Wales. So far as the paleontological evidence is concerned, Whitehouse would consider the Neerkol Series part and parcel of the underlying Rockampton Series, and it may later be considered better to term it the Upper Rockampton Series. It is, however, separated by a massive basal conglomerate from the Rockhampton Series proper beneath. The Rockhampton Series, some 7,000 feet thick, is of the same age in its upper part as the Burindi Series, of New South Wales, that is, Viséan, but its lower strata contain Tournaisian fossils such as the cephalopods *Protocanites planorbiformis, Pseudarietites ammonitoformis, Pseudarietites dubius.* This is the only part of Australia where Carboniferous rocks as old as Tournaisian have been recorded.

The whole of the Rockhampton Series is largely formed of andesitic tuffs, tuffaceous laminated black cherts, grits and andesities, and, in the upper beds, oolitic limestones.

The Viséan portion has a rich coral fauna, in which *Amygdalophyllum*, *Lithostrotion* and *Michelinia* are conspicuous. Other noteworthy fossils are *Hexagonella crucialis* and *Archimedes* sp. nov. (the first record of this interesting genus in Australia).

E. YATTON DISTRICT, QUEENSLAND

(See section 2, figure 3)

In the next section, northwards at Yatton, in Queensland, the *Eurydesma cordatum* beds are represented, and *Monilopora* with *Cladochonus* maintains its normal horizon beneath the above zone.

At Mount Britton the big *Strophalosia* bed, of the Muree beds in the Upper Marine Series of New South Wales, is well developed. The equivalent of the Greta Coal-measures is not developed, but a few hundred feet below that horizon there occurs a cephalopod which Whitehouse provisionally refers to *Paragastrioceras* (?), a zone fossil in the Northern Hemisphere for the uppermost Carboniferous.

It may be noted that at one horizon about 500 feet lower, and another 3,000 feet lower than the *Paragastrioceras* (?) zone, *Glossopteris* occurs in shales intercalated in a sequence of andesites and rhyolites. Again, if the determination of *Paragastrioceras* is correct, *Glossopteris* would here seem to descend into the Upper Carboniferous.

F. BOWEN DISTRICT, QUEENSLAND

(See section 1, figure 3)

At the northernmost section in Queensland, that of Bowen (number 1), the Upper Bowen fresh-water beds with numerous coal seams, much fossil *Dadoxylon* occurring as large silicified logs in tuffaceous shales, can be definitely correlated with the Upper Coal-measures of New South Wales.

The Middle Bowen Series, 2,400 feet thick with its big *Strophalosia* zone and dumped glacial erratics can be definitely correlated with the Upper Marine Series of New South Wales. It contains a well-marked zone in which *Derbyia* is abundant. This genus has not yet been recorded from the Hunter area. The Collinsville Coal-measures can be correlated with the Greta Coal-measures of New South Wales, especially where much volcanic rock is interbedded with these latter, as at Raymond Terrace, northwest of Newcastle, New South Wales.

A thickness of about 2,000 feet of basalts and andesites is interstratified in these Queensland Coal-measures, and at the base of those volcanic rocks is more coal, with *Glossopteris,* the Mount Devlin Coal-measures. These can be correlated with the coal-measure zone containing Garretts Seam, 7 miles northerly from Raymond Terrace, New South Wales.

G. TASMANIA

(See section 7. figure 3)

If now we travel southward and reach Tasmania, we find sections which correlate fairly well with those of the Hunter District of New South Wales. Immediately above the *Glossopteris*-bearing Upper Permian Coal-measures, the equivalents of the Upper Coal-measures of the Kamílaroi of New South Wales, is the Knocklofty sandstone. This has yielded a fossil bone originally described as the humerus of a Labyrinthodont, but Professor D. M. S. Watson considers that it is a femur which appears to belong to a reptile.

Watson states:

> "The bone is a femur and is identical in its morphology with those of the *Captorhinidæ* of the Lower Trias of South Africa and Europe. Both families belong to the order *Cotylosauria.* It is impossible to determine the age of this specimen."

Nevertheless on the whole a Lower Triassic age seems indicated by this reptilian remains for the Knocklofty sandstones which immediately overlie the newest of the *Glossopteris*-bearing coal-measures of Tasmania.

Equivalents of the Upper Marine Series of the Hunter can be identified in Tasmania with horizons of dumped erratics. The coal-measures of Preolenna, Railton and Bruni Island are certainly identical with the Greta coal-measures of New South Whales.

At Maria Island, off the east coast of Tasmania, there is a wonderful development of the main *Eurydesma cordatum* horizon. This shell occurs in such profusion in the marine clayey sediments as to convert them into argillaceous limestones, used for manufacturing portland cement.

Great numbers of ice-borne erratics are scattered throughout the lower part of the *Eurydesma cordatum* beds. It may be tentatively suggested that this is the equivalent of the Allandale small glacial horizon of the Hunter district and the Dilly-Springsure horizons of Queensland, all associated with the main zone of *Eurydesma cordatum.*

The chief glacial beds of Kamílaroi age in Tasmania are situated at Wynyard. They are 1,200 feet in thickness, and show at least three ice-

striated pavements in the tillites themselves. Apparently the till was frozen when the ice readvanced over it, so that the firmly frozen-in boulders were all rasped down together, so that the direction of their striæ exactly coincided with that of the movement of the ice. The Wynyard glacial beds are almost certainly identical with those of Lochinvar in New South Wales, and can confidently be correlated with the glacial beds of Bacchus Marsh, and many other localities in Victoria, and those of the Inman Valley and Halletts Cove in South Australia.

The Wynyard glacial beds underlie a marine series of Lower Marine type, but no systematic collection has yet been made of the fossils of this horizon. The marine series underlies the Preolenna Coal-measures of Greta age.

It may be added that dumped erratics are quite numerous in Tasmania on horizons which appear to be the equivalents of the Upper Marine glacial horizons of New South Wales.

Outlying patches of the Wynyard glacial beds occur in many parts of Tasmania lying on what seems to have been, at the time, a surface of low relief, so there can be but little doubt that, when the ice was at its maximum, practically the whole of Tasmania was under a more or less continuous ice-sheet.

There can be no doubt, we think, that the Wynyard glacial beds of Tasmania are not as old as the Kuttung of New South Wales but are approximately on the horizon of the Lochinvar glacial beds of the Hunter area in New South Wales.

H. VICTORIA

(See section 8, figure 3)

If now one crosses from Tasmania to Victoria, one is impressed with the widespread character and the intensity of the glaciation there.

So far evidence of only one, but prolonged and intensive, glaciation has been met with, namely, that of the Lochinvar glacial beds, whereas in Tasmania there are distinct proofs of the three glacial horizons, namely, Lochinvar with, at a higher level, the *Eurydesma cordatum* zone, and the Branxton, and perhaps the Bolwarra zone.

This glacial horizon is known in Victoria as that of the Bacchus Marsh glacial beds. Detailed sections of the Wynyard and of the Bacchus Marsh glacial beds have been given by us already (1).

The total thickness of the Victorian glacial beds is estimated as over 1,600 feet. They are capped by about 30 feet of sandstones containing leaves of *Gangamopteris* in abundance. These beds are in perfect con-

formity with the underlying glacials, and there does not appear to be any break in the sequence from the top of the glacial beds into the *Gangamopteris* sandstones and shales. It may be provisionally concluded that *Gangamopteris* was a hardy plant which existed close to the edge of the great Kamílaroi (Permo-Carboniferous) ice-sheet. The close association of *Gangamopteris* with tillites recalls the observation near Vereeniging in South Africa, in the Transvaal, of the leaves of *Gangamopteris* among the boulders of the Dwyka conglomerate, actually where these are resting directly on a striated pavement of older rock.

Above the *Gangamopteris* sandstones is some thickness of redistributed ("winnowed") tillite probably marking a nonsequence, and, above this, are a thin series of beds containing Triassic plants.

Recent researches have revealed the fact that these Victorian glacial deposits underlie many of the Tertiary and Mesozoic sedimentary areas, and also occur under the basalts and sediments of many of the Tertiary "deep leads," as recently described by D. J. Mahony.

As in the case of Tasmania, Victoria seems to have been more or less covered by a great ice-sheet in the Lochinvar time of the Hunter district of New South Wales. On the whole the surface of the ground over which the ice moved appears to have been one of low relief. Apparent over-deepened valleys are present in places, perhaps developed not by Alpine glaciers, after the breaking up of the ice-sheet into individual glacial tongues, but through the ice-sheet having invaded old land valleys—not exceeding about 1,000 feet in depth.

The sections of the Bacchus Marsh and Dwyka (South Africa) glacial beds show that there are in both countries apparently three principal tillites, and one is disposed to correlate all three with one another on the internal evidence of the structure of the glacial beds themselves, even apart from the evidence of the fossils.

I. INMAN VALLEY, SOUTH AUSTRALIA

(See section 9, figure 3)

In South Australia, in the Inman Valley, the glacial beds, formed of sandy tillites and sandstones with or without boulders, attain a thickness of at least 1,000 feet in the old glacial valleys, for here, as well as at Bacchus Marsh, there is evidence of late Paleozoic over deepened valleys. Wonderful examples of the old glacial landscape are being rediscovered

there through the progressive erosion of the glacial beds from off the very hard striated pavements. W. Howchin (14) states:

> "The striated pavements show that the ice traveled in a northwesterly direction and the body of the ice was so great that it was not in the least diverted from its course by hills which are now 900 feet above sealevel and 1,800 feet above the floor of the glacial valley."

J. COLLIE COALFIELD, WESTERN AUSTRALIA

In regard to the Permo-Carboniferous strata of Western Australia, it may be noted that, at the southwest extremity of that State, there are situated the infaulted blocks of the Collie coalfield, and the small Wilga coalfield. The total thickness of the Collie Coal-measures exceeds 2,000 feet, with a total thickness of coal of about 137 feet. The coal seams appear to be of drift, or of lacustrine origin.

The following is an approximate descending section:

Feet	
150 (about)	Upper or Cardiff Coal-measures
500 (about)	Strata with thin coals
250 (about)	Middle or Collie Burn Coal-measures
700 (about)	Strata with thin coal seams and *Foraminifera* and *Ostracoda*
140 (about)	Lower or Collie stage
200	Strata without (?) coal
1,940 (total)	

The following is a list of the Foraminifera (15):

Endothyra sp.
Valvulina plicata
Bulimina sp.
Truncatulina haidingeri
Pulvinulina, cf. *exigua*

It may be suggested that the strata overlying the Lower or Collie Coal-measures may perhaps be the equivalent of the Upper Marine Series of the Hunter district. If this is so, the Lower Coal-measures would be near to the Greta horizon.

Glossopteris and *Gangamopteris* are fairly abundant throughout the whole series. *Vertebraria* occurs sparingly.

These coals, unlike the Paleozoic coals of Eastern Australia, are hydrous, containing from 17 to 25 per cent of moisture. This feature is due to the extreme rigidity of the Pre-Cambrian shield on which they rest, which has protected them against compression.

K. IRWIN RIVER DISTRICT, WESTERN AUSTRALIA

(See section 10, figure 3)

One of the most important and interesting sections of the Permo-Carboniferous strata of Western Australia is afforded by the Irwin River coalfield, the descending section of which is as follows:

Feet	
450	Mudstones with *Aviculopecten* and *Anthracosia*-like shells and occasional fish; small erratics occur here
133	Coal-measures containing an aggregate of 20 feet 9 inches of coal rather inferior and hydrous, moisture 18 to 24 per cent, and the following plants: *Phyllotheca* sp., or *Schizoneura* *Sphenopteris lobifolia* *Glossopteris browniana* *G. indica* *G. ampla* *Gangamopteris* *Noeggerathiopsis* sp. *Bothrodendron* sp.
85	Sandstones and lenticular limestones, very rich in remarkably well-preserved brachiopods. *Chonetes pratti* abundant
1,100	Olive shales and gypseous mudstone with selenite, somewhat saline. No fossils found
600	Buff beds with most abundant *Paralegoceras jacksoni* near top of this stage
500	(about) Gray shales somewhat saline, with one internal cast of *Platyschisma*, or *Keenia* (?)
200	(about) Tillite with erratics up to 60 tons in weight
450	Gray to green soft shales and lenticular argillaceous limestones
150	Basal fluvio-glacial conglomerate
	Violent unconformity
	Proterozoic (?) chocolate shales and limestones

Bothrodendron has been recorded from the Ecca Coal-measures of South Africa, the age of which is Permian, as is also in all probability that of the Irwin River Coal-measures.

From the strata immediately below the Irwin River Coal-measures the following have been collected:

***Nubecularia lucifuga*, var. *stevensi*, *Pleurophyllum australe*, *Productus semireticulatus*, *Productus subquadratus* (*Taeniothaerus*, gen. nov. Whitehouse), *P. tenuistriatus*, var. *foordi*, *P. undatus*, *Seminula subtilita*, *Reticularia lineata*, *Chonetes pratti*, *Diclasma* sp. *Fenestella fossula*, *Aviculopecten sprenti*, *Conocardium* sp. *Stutchburia* cf. *S.* (*Pleurophorus randsi*, Eth. fil) *Bellerophon costatus*, Trilobites (undescribed).**

By far the chief interest of this fauna centers in the highly important cephalopod *Paralegoceras jacksoni*. This is separated from the above beds by about 1,100 feet of nonfossiliferous (?) olive-colored gypseous and somewhat saline shales. These cephalopods are up to a foot in diameter and occur all together and touching one another in a stratum about six inches in thickness. These were all deposited in a remote bay of the Tethys. They should form specially valuable geological chronometers for adjusting the time value of the Kamilaroi marine fauna of eastern Australia to that of a similar fauna in the old world.

Apparently a vast fleet of these cephalopods was drifted by some relatively warm current, from the north into the bay, then probably more or less occupied by ice, where are now the sub-Greta marine strata of the Irwin coalfield, and there these animals perished literally in millions. These cephalopods have their sutures, in many instances well preserved. Through the kindness of A. Gibb Maitland, F. Glauert and Professor E. de Courcy Clarke one of the authors was able to take to Cambridge University a fine collection of picked specimens in 1926. These were specially studied by Dr. Dighton Thomas (16) at Cambridge and at the British Museum, and his final conclusion is as follows:

> "If all the characteristics be considered, *Paralegoceras jacksoni* finds a close analogue in the Pennsylvanian ammonoid *Gastrioceras excelsum* (Meek) from the middle coal-measures of Arkansas and east Kansas. . . . *Paralegoceras jacksoni* has affinities then, not with Permian species, but with American Pennsylvanian species, as suggested by Haug, and would therefore indicate for the Irwin River goniatite bed an Upper Carboniferous (Upper Pennsylvanian) age."

We understand that Dr. Spath of the British Museum agrees with Thomas' conclusions.

Writing in *Nature* Thomas states in regard to the above cephalopod, "Its affinities are with Upper Carboniferous forms, and as far as one may rely on this species it supports an Upper Carboniferous age for the bed which yields it in large numbers."

At about 1,100 feet lower in the series is a very strongly developed tillite or boulder clay, perhaps 200 feet in thickness. A. Gibb Maitland (formerly government geologist of Western Australia) considers that this glacial bed is on the horizon of the "Lyons conglomerate" which is so extensively developed near the base of the Permo-Carboniferous beds of western Australia farther north. As the Lyons conglomerate has been proved to persist for hundreds of miles, it is most unlikely that it was wanting in the Irwin River coalfield. Apart from the small erratics

in the mudstones overying the Irwin River coal seam no other glacial horizon is known in that area except the tillite just mentioned.

So far therefore as the evidence of this cephalopod is concerned, the age of the main glacial beds of the Irwin River, which are almost certainly on the Lyons conglomerate glacial horizon, is Upper Carboniferous, and not even at the top of the Upper Carboniferous, but nearly halfway down in that series, according to Dighton Thomas.

L. ARTHUR RIVER DISTRICT, WESTERN AUSTRALIA

(See section 11, figure 3)

The next section, that of the Arthur River in Western Australia, is of special importance on account of the remains of a large shark, *Helicoprion* or *Toxoprion*, from some unknown horizon above the Lyons conglomerate, which has been discovered in that area. The general section is approximately as follows:

Feet	
100–200	Sandstones, grits and fine conglomerates with fossiliferous concretions containing *Spirifer Athyris* (?) *Productus* and *Strophalosia*.
100 (about)	Fossiliferous sandy and flaggy limestones containing the following fossils: *Hexagonella* (*Evactinopora cruciales*), *Rhombopora tenuis*, *Athyris maclcayana*, var. *Productus semireticulatus*, *Aulosteges barracoodensis*, and *Diclasma* sp. ind.
20 (about)	"Lyons conglomerate" with glaciated boulders from an inch up to several feet in diameter.
100 (about)	Sandy and flaggy limestones apparently without fossils, passing at their base into a quartz conglomerate. This last rests with strong unconformity on Pre-Cambrian granite.

The form *Aulosteges* strongly suggests a Permian age for the marine boulder beds immediately and conformably below the limestones and limestone conglomerate. Dr. Whitehouse, however, has suggested that this *Aulosteges* is of a primitive type. He also states (17):

"The various Permo-Carboniferous localities from the Irwin to the Minilya River have yielded '*Taeniothaerus*', a new genus proposed by Whitehouse for forms either identical with *T. subquadratus*, or with a new species which has been confused with *Aulosteges baracoodensis*. . . . The type of *A. baracoodensis* (18) is an Aulosteges; but the forms included later by Etheridge in that species are very distinct and belong to *Taeniothaerus*, a genus intermediate between *Pustula* and *Aulosteges*."

Whitehouse admits therefore that the type specimen *Aulosteges baracoodensis* which at the Arthur River overlies the marine boulder bed is a genuine *Aulosteges*.

It may be added that the forms now considered to be *Taeniothaerus subquadratus* by Whitehouse from the Wooramel River area, described by Etheridge as *Aulosteges,* in the above reference have adhering to one of their valves *Strophalosia complectens* (Eth. fil.) compared by him with the Tasmanian form *S. jukesi,* and also with *S. lamellosa* (Geinitz) of the Permian (19).

In the valley of the Arthur River a fossil has been found, *Toxoprion* or *Helicoprion,* the original of which is in the collection of the Geological Survey of Western Australia at the National Museum, Perth. Schuchert very rightly stresses the importance of this, but terms it without qualification a *Helicoprion.* The specimen was originally described as *Edestus davisii,* by H. Woodward (20), but subsequently Sir A. Smith Woodward, in his catalogue of the fossil fishes in the British Museum (21) referred it to *Helicoprion.*

One of us (T. W. E. D.) has attempted to summarize the matter recently (22).

Obviously the greatest possible importance should attach to any remains of so rapid a migrator as that giant extinct shark; and if its exact horizon in the series were known, it would supply invaluable evidence. *Helicoprion* is, of course, specially characteristic in the Artinsk of Russia, and in the Lower Permian of Japan and in the Upper Productus-limestone of Chidru in the Himalayas. Any strata containing its remains might surely be classed as Permian rather than Carboniferous. Unfortunately the specimen, found in the Arthur River Valley, occurred in a loose concretion. It certainly came from a horizon above that of the basal glacial beds. While the exact geological horizon of the specimen is in doubt, on account of its having been picked up loose in the river bed, the nature of the original structure of the whole fossil and its affinities, is also considered doubtful, for the specimen, if *Helicoprion,* is only a small fragment of the whole. If it ever formed part of the outer spiral of the median dental apparatus of a *Helicoprion,* the fragment would represent less than a fifth part of the original, symmetrically coiled spiral. Partly in view of the fact that there is no evidence that the Australian specimen ever had the form of the elaborate spiral of a *Helicoprion,* C. R. Eastman, in 1902 (23) referred the Australian specimen to *Campyloprion,* a Carboniferous genus. Still later (1910) Oliver P. Hay (24) created a new genus for Bashford Dean's type, *Edestus lecontei,* namely, *Toxoprion,* to which he referred H. Woodward's *Edestus davisii,* from western Australia. This conclusion has been accepted by A. Gibb Maitland, our

chief authority on the geology of Western Australia. *Toxoprion* is a Carboniferous genus occurring in rocks of that age in Nevada. Thus two American paleontologists remove this western Australian fish fragment from the Permian genus *Helicoprion,* and place it among Carboniferous genera.

A. Gibb Maitland assures us that in the Arthur River Valley, where the fossil was found, only the equivalent of the Lower Marine Series of the Hunter area in New South Wales is represented. This occurrence of *Helicoprion* (?) is obviously a matter of vital importance for the whole paleontology and stratigraphy of the "Permo-Carboniferous" rocks of Australia, and every effort should be made to discover the exact horizon of its occurrence, and to ascertain whether it had a spiral like *Helicoprion,* or resembled *Toxoprion,* or some allied Upper Carboniferous form.

M. MOUNT MARMION DISTRICT, WESTERN AUSTRALIA

(See section 12, figure 3)

As regards section number 12 of the Mount Marmion, Mount Wynne, Mount Pierre areas, in the Kimberley region of Western Australia it would appear that the Greta Coal-measures horizon may be represented by a seam 11 feet thick, of alternating layers of coal and clay shale. *Monilopora nicholsoni, Cladochonus temeicollis* and *Favosites marmionensis* are fairly abundant on a horizon below the coal-measures, but apparently above the horizon of the Lyons conglomerate (marine glacial boulder bed). The glacial bed, the Lyons conglomerate, is about 30 feet in thickness and contains many beautifully striated boulders of local origin.

At the Poole Range, near latitude 18° 50′ south, longitude 125° 45′ east, T. Blatchford and H. W. B. Talbot have recently observed the fact that small silicified stems of wood, identified by Dr. A. B. Walkom as *Dadoxylon,* occur immediately above the glacial beds, and also occur in position of growth underneath the glacial beds. This is the first time that coniferous wood has been found anywhere in Australia, or for the matter of that, anywhere in the world, in direct association with the main glacial horizon, the probable equivalent of the Lochinvar glacial beds of the type district of the Lower Hunter in New South Wales. In this area, as at the Irwin River, there are several hundred feet of strata conformable to the glacial beds and underlying them, but so far no fossils have been found in them. The next fossiliferous strata beneath these beds are of Burindi (Viséan) age.

N. PORT KEATS DISTRICT, NORTHERN AUSTRALIA

(See section 13, figure 3)

At the Port Keats Section marine strata of Upper Marine (Middle Permian?) age overlie some black shales containing *Glossopteris* and *Noeggerathiopsis,* which probably are near to, if not on, the horizon of the Greta Coal-measures. The polyzoan *Dybowskiella geei* is well preserved, and is frequent in these strata. The genus is characteristic of the *Productus* limestone of the Salt Range in India.

There can be little doubt that all the rocks penetrated in the Port Keats bore are of Permian age. The table below attempts to correlate the Kamilaroi rocks of Australia:

SUMMARY OF KAMILAROI SYSTEM

One may now tentatively deduce the following from the evidence above given:

The paleontological evidence suggests that the Kamilaroi ("Permo-Carboniferous") strata of Australia fall into two provinces—a western province which is Tethyan, the fauna and flora of which show strong affinities with those of Eurasia, and an eastern province which is Pacific rather than Tethyan. The eastern province is divisible into two subprovinces, a northeastern Australian province and a southeastern province. These are set out on the table below:

Suggested Provinces of the Kamilaroi ("Permo-Carboniferous") System of Australia and Tasmania

Western Province	Eastern Province	
Darwin to Cape Leuwin in northwest Australia	North Queensland to Tasmania	
Tethyan	Pacific	
× *Monilopora nicholsoni*		
× *Taeniothaerus (Productus subquadratus)*		
Toxoprion (Helicoprion?)		
Paralegoceras		
	Northeastern subprovince, northern Queensland to Kempsey, New South Wales	Southeastern subprovince, Hunter area, New South Wales to Tasmania
	× *Monilopora nicholsoni*	
	× *Taeniothaerus*	
	+ *Eurydesma cordatum*	+ *Eurydesma cordatum*
	Paragastriocceras (?)	

Tentative Correlation and Chronology of the Kami

		New South Wales		Queensland	
Upper Permian	Kamilaroi System	Upper Coal-measures. {Newcastle / Tomago	Bowen Series	Upper Bowen Coal-measures	Upper
		Upper Marine series. Big Strophalosia bed		Middle Bowen. {A marine series / Big Strophalosia bed / One glacial horizon	Upper erra
		Fifth Glacial. {B. Two glacial horizons / A.			
Lower Permian		Lower Coal-measures—Greta		Base of Middle Bowen {Collinsville and Mount Devlin	Irwin
		Fourth Glacial {Farley stage / Rutherford stage / *Eurydesma cordatum* banks / Small glacial horizon		Lower Bowen. {Farley zone / *Eurydesma cordatum* banks and Springsure glacial horizon	Farley
Upper Carboniferous		Lower Marine series. Third Glacial. {Lochinvar stage—Gangamopteris glacial beds		*Monilopora nicholsoni* Early *Glossopteris-Gangamopteris* flora of Springsure, Dinner Creek, etcetera. Gympie series with Monilopora, dwarf marine fauna and erratics, at Texas, etcetera.	*Monil* *Favosi* *Syring* (Hu *Parale* Glacia Kim ciate and

The essence of this correlation, as relates to the dividing line between Permian and Carboniferous, may be sta

	South Australia	Victoria	Tasmania	New South Wales
Permian			*Eurydesma cordatum* banks Glacial erratics	*Eurydesma cordatum* banks Glacial erratics
Carboniferous	Inman Valley glacial beds	Bacchus Marsh Gangamopteris beds and glacial beds	Wynyard glacial beds	Gangamopteris beds near Loc Lochinvar glacial beds

rrelation and Chronology of the Kamilaroi (Permo-Carboniferous) Rocks of

Queensland	Western Australia	
Coal-measures	Upper Coal-measures {Cardiff / Collie Burn	
{A marine series / Big Strophalosia bed / One glacial horizon	Upper Marine series—with small glacial erratics	
{Collinsville and Mount Devlin	Irwin River and Collie Coal-measures	
{Farley zone / *Eurydesma cordatum* banks and Springsure glacial horizon	Farley zone (?). {Aulosteges / *Toxoprion* or / *Helicoprion*	
holsoni *ris-Gangamopteris* flora e, Dinner Creek, etcet- with Monilopora, dwarf and erratics, at Texas,	*Monilopora nicholsoni* *Favosites marmionensis* *Syringopora reticulata*, var. *patula* (Hunde) *Paralegoceras jacksoni* Glacial beds of Irwin River, and of Kimberley Region, the latter associated with Dadoxylon both below and above the glacial beds	

mian and Carboniferous, may be stated as follows:

	New South Wales	Queensland
	Eurydesma cordatum banks Glacial erratics	*Eurydesma cordatum* banl Glacial erratics
	Gangamopteris beds near Lochinvar Lochinvar glacial beds	*Monilopora nicholsoni* *Glossopteris - Gangamopter* Springsure, Dinner Cre glacial erratics of Gym

	Tasmania	Victoria	South Australia
rn	Mount Pelion, etcetera, *Glossopteris* Coal-measures		
glacial	Upper Marine Series with small glacial erratics		
sures	Latrobe Coal-measures and Tasmanite Mount Pelion "Pelionite"		
	Eurydesma cordatum banks Glacial erratics		
ula d of asso-elow	Wynyard glacial beds	Bacchus Marsh Gangamopteris beds and glacial beds	Inman Valley glacial beds

Queensland	Western Australia
atum banks	*Aulosteges?* *Toxoprion* or *Helicoprion?*
holsoni *ngamopteris* beds, Dinner Creek, etcetera, s of Gympie series	*Monilopora nicholsoni*, *Paralegoceras jacksoni.* Glacial beds of Irwin River and of Gascoyne and Kimberley areas, the last with *Dadoxylon*

It will be noted that in the western province *Monilopora nicholsoni* occurs without any *Eurydesma;* in the northeastern subprovince both *Monilopora nicholsoni* and *Eurydesma cordatum* are present, while in the southeastern subprovince *Eurydesma cordatum* is characteristic, but *Monilopora* appears to have been absent. Thus by means of these two fossils, both of which are characteristic and of restricted range, the Kamílaroi strata of western Australia can be correlated with those of Queensland and northern New South Wales (New England District), and the similar rocks of southeastern Australia and Tasmania by means of *Eurydesma cordatum* can be linked up with those of Queensland, and through Queensland with those of Western Australia.

The authors think it only fair to state that while all Australian geologists, who are familiar with the sequence of the Kuttung, entirely agree with the authors as to the inclusion of a great glacial series in the Rhacopteris beds of the Kuttung, they are not all in agreement with the authors as to their chronological interpretation of the strata of the Kamílaroi system.

For instance, in regard to the inclusion of the sub-Greta Permo-Carboniferous marine beds entirely in the Permian, the weighty opinion of the former government geologist of Western Australia, A. Gibb Maitland (25) may here be quoted:

"The Permo-Carboniferous rocks of Western Australia have yielded a rich assemblage of fossils, of which lists have been given above, and the fauna very closely resembles that of India.

"According to recent researches into the paleontology of the Salt Range Beds of India, it appears that *Spiriferina lata*, McCoy, of Western Australia is hardly to be distinguished from *Spiriferina infer*, Waag, occurring in the Lower Productus limestone. *Spirifer hardmani* is merely a variety of *Spirifer marcoui* occurring at Amb; *Athyris macleayana* is identical with *Athyris capillata; Aulosteges baracoodensis*, likewise, can hardly be distinguished from *Aulosteges medlicottianus*, and is closely allied to *A. dalhousi*, Davidson; *Productus tenuistriatus*, var. *foordi*, Eth., from the group *Productus tumidus. Productus bellus*, Eth. Fil., from Mount Marmion, in Kimberley, is a small shell, quite distinct from anything occurring in the Permo-Carboniferous strata of Eastern Australia, which has a very strong affinity with the small Indian species *Productus asperulus*, Waagen. The *Conularia* from the Byro Plains though allied to the two species *C. levigata*, Morris, and *C. inornata*, Dana, occurring in the Permo-Carboniferous beds of Eastern Australia, shows a much closer affinity to the Indian form *C. warthi*, Waag, occurring in the basal speckled sandstone beneath the Productus limestones in the Salt Range beds. The fossils from the Irwin River beds also show an intimate relationship to those of the Salt Range, namely, *Productus subquadratus* belongs to the series of

Productus abichi; Productus undatus is like *P. opunta*, and *Productus tenuistriatus* resembles *P. tumidus.*

"More detailed paleontological research may, of course, reveal further connecting links, but so far as the evidence at present goes, it seems quite clear that the strata containing the glacial boulder beds of India are homotaxial with those of Western Australia, and appear to have been deposited in the same great marine area with more or less free communication between its different parts."

The question here might not unreasonably be raised, as to which of the three glacial horizons of the Kamílaroi strata of the Hunter District, may the Talchir boulder beds of India belong; as, for example, do they belong to Number 5, Number 4 or Number 3. If to Number 4, then in our opinion they may be of Lower Permian Age. If to Number 3 they are more likely to be referable to Upper Carboniferous time.

It may be added that W. S. Dun, paleontologist to the Geological Survey of New South Wales, inclines to the view that the Permian marine fauna can be carried down probably to the base of the Lochinvar glacial shales. He bases his opinion on the character of the brachiopods, a group which he has long studied, so that no little weight should be attached to his views. He also stresses the point that *Eurydesma hobartense* occurs at Lochinvar immediately above the glacial beds in strata perfectly conformable with them. At the same time he admits that the specimens are only about two-thirds the normal size of *Eurydesma hobartense.*

On the other hand Professor Seward has stated (26):

"It is difficult to believe that events which occurred during the latter half of the Carboniferous period are entirely lacking in the geological records not only of Australia, but of India and South Africa. The more probable view, in my opinion, is that the Lower Marine Series (of the Hunter area, New South Wales, T. W. E. D.), and the corresponding strata in Western Australia containing *Paralegoceras*, are homotaxial with the Upper Carboniferous system in Europe and North America."

Dr. H. Dighton Thomas, as has already been pointed out, concludes in regard to *Paralegoceras jacksoni* which occurs in such profusion in the sub-Greta "Lower Marine Series" of the Irwin River coalfield, Western Australia, that it is of Upper Carboniferous age.

Against this positive and very definite conclusion regarding *Paralegoceras jacksoni* must be set the more doubtful evidence of

(*a*) The occurrence of an apparently primitive type of *Aulosteges* in strata at the Arthur River, Western Australia, in strata not very high stratigraphically above the basal glacial beds the "Lyons conglomerate."

(*b*) The occurrence in a loose concretion at the same locality of a specimen of *Toxoprion* or *Helicoprion*.

If the specimen is referable to the latter genus, then it is a fragment representing only about one-fifth of the typical median dental apparatus of that wonderful shark. In any case, whether it belongs to the Carboniferous genus *Toxoprion*, or to the Permian genus *Helicoprion*, its original horizon is in doubt, beyond the fact that it probably was derived in the Arthur Valley from sub-Greta strata, the age of the latter being considered to be Lower Permian.

(*c*) Lastly, many of the brachiopods show affinities with those of the Salt Range, India, such as those enumerated above by A. Gibb Maitland.

In view, nevertheless, of the cephalopodan evidence of *Paralegoceras jacksoni*, and the almost certain evidence of a *Paragastrioceras* in the "Lower Marine" beds of Queensland, we have decided, tentatively, to group these horizons, which are also characterized by the Carboniferous genus *Monilopora*, with some upper portion of Pennsylvanian time. At the same time until much more stratigraphic and paleontologic work is done, particularly on the "Lower Marine" Kamílaroi rocks of Western Australia, which are so closely allied to those of Eurasia, it would be premature to attempt to make a final classification of a group of rocks containing such an intricate admixture of Carboniferous and Permian types—the admixture being complicated no doubt by many migrations and modifications of marine faunas resulting in part from the recurrences of so many ice ages.

All that the authors would hope for the scheme set out on the table of vertical sections is that it may supply a reasonable hypothesis for the investigation by future workers of a very complex geological problem.

The Tectonic Evidence and Argument

The opinion is growing that if any pronounced diastrophic movements of the earth's crust have taken place at any particular locality similar movements will be found to have occurred contemporaneously at many other portions of the earth.

If, then, crustal diastrophism is, in a general way, worldwide, such diastrophisms should have a distinct chronological value and use for correlation.

According to Stille the epochs of diastrophism, from the close of Devonian time to the end of the Permian period, are now fairly well known; and if the Pfälzian disturbance at the close of Permian time—

in many places not strongly marked, or entirely absent—be omitted there remain four diastrophisms. These in descending order of age are as follows: Saalian, Asturian, Sudetic, Bretonian. The Saalian disturbance separates the Upper Rotliegend, Middle Permian, from the Lower Rotliegend, Lower Permian. In the Hunter area of New South Wales there is a marked disturbance in evidence at the top of the Lower Permian, the "Upper Marine Series" and coming between it and the Middle (?) Permian Tomago Coal-measures. This is shown on Section 6 of figure 3, by the thick black oblique line separating the Tomago Coal-measures from the Upper Marine Series. This disturbance, in Australia, may be termed the Aellalong disturbance. The next disturbance, the Asturian, separates the upper portion of the Upper Carboniferous strata, the Ottweiler and the Stephanian Coal-measures, from the Lower Division of the Upper Carboniferous, such as the Westphalian, the Saarbruck Coal-measures, the Waldenburg Series, etcetera. Paleontological evidence favors the view that the uppermost strata of the Kuttung Series of New South Wales are very close in age to the Ostrau-Waldenburg strata of Silesia, the Millstone grit of England and the Upper Pottsville Series of the United States of America.[3]

While no angular unconformity has as yet been observed at the top of the Kuttung Series, there is certainly a strong paleontological and lithological break with a considerable amount of transgression. This break may be termed the Lochinvar break, and seems to correspond fairly in geological time with the Asturian disturbance.

Next in descending order is the Sudetic disturbance. This according to Stille intervenes between the top of the Viséan, and the base of the Upper Carboniferous, as, for example, the base of the Westphalian, Waldenburg Series, etcetera. In New South Wales, in the Hunter area, there is evidence of a strong break but of an epeirogenic rather than an orogenic character, at the top of the Burindi (Viséan). This may be termed the Wallarobba disturbance.

The Bretonian disturbance occurred in epi-Devonian time. An exact equivalent of this in New South Wales has been termed by one of us (C. A. S.) the Kanimbla disturbance. It was accompanied by widespread intrusions of batholiths of granite.

The following table shows this tentative correlation of the late Paleozoic disturbances of Eastern Australia with those already described by Stille:

[3] See Walkom's opinion, 1, p. 287.

Formation	Age	Extra-Australian disturbances	Australian disturbances
Epi-Lower Rotliegend	Epi-Lower Permian	Saalian Orogeny	Aellalong Orogeny
Epi-Waldenburg and Pre-Stephanian	Upper part of Middle Carboniferous	Asturian Orogeny	Lochinvar break, with widespread crustal submergence with some local uplift
Epi-Visean and Pre-Waldenburg	Lower part of Middle Carboniferous	Sudetic	Wallarobba epeirogenic disturbance
Epi-Famennian	Epi-Devonian and Pre-Tournaisian	Bretonian	Kanimbla granitic intrusion epoch

Stille states that in no part of the world, so far, has any serious crustal movement been recorded between the top of the Carboniferous system and the base of the Permian. The authors consider that similar conditions obtained in Australia.

Conclusions

From the evidence given in this paper it will be obvious that the Upper Paleozoic glaciation of Australia was not confined to a limited period of geological time, such as the Middle Permian, as claimed by Schuchert, but had its beginnings in the Kuttung epoch (Kulm) and continued on until the top of the Lower Permian epoch (Upper Marine epoch) when it finally disappeared. In the strata deposited during this time in Eastern Australia there occur five distinct glacial horizons. Each of these horizons gives evidence of an epoch of pronounced (though not necessarily equally intense) glacial conditions, probably separated from one another by periods of a milder climate. In the case of glacial horizons four and five, there intervened a period during which an important series of coal-measures were deposited. This break represents a very decided inter-glacial epoch, and it may be that a complete cessation of glacial conditions occurred at that time.

It has been shown that the Carboniferous system of Australia includes the following subdivisions:

a. The Burindi Series, a marine formation of from 5,000 to 10,000 feet in thickness of definitely Lower Carboniferous (Viséan) age.

b. The Kuttung Series, a terrestial formation with a thickness of about 9,600 feet containing undoubted glacial beds associated with a *Rhacopteris* flora. This formation is of Middle Carboniferous age, beginning in the upper part of the Lower Carboniferous (Culm), and extending probably into the lower part of the Upper Carboniferous (Westphalian).

c. The Lochinvar Series, including the lower part, 2,700 feet in thickness, of what has previously been known as the Lower Marine Series, and extending to the base of the main *Euredesma cordatum* beds. This series of strata is dominantly marine in origin, and in Western Australia it contains such Upper Carboniferous species as *Paralegoceras jacksoni, Monilopora nicholsoni, Syringopora favosites,* etcetera, and is characterized also by the appearance in some localities of the *Gangamopteris-Glossopteris* flora. The placing of strata containig this flora into the Upper Carboniferous is not limited to Australia; Du Toit has already drawn attention to the very close association of the *Rhacopteris* and *Glossopteris* floras in conformable strata in South America; and at Wankie in South Africa we get the association of the *Glossopteris* flora with such Stephanian forms as *Sphenophyllum oblongifolium, Pecopteris arborescens, Pecopteris unita,* etcetera.

It will obviously be very many years yet before the world relations of

the Kamílaroi (Permo-Carboniferous) system of Australia are known with any degree of accuracy. Much help may be expected from a systematic mapping of the chief Kamílaroi localities in Western Australia, as in that State there is an extraordinarily well preserved marine fauna of Tethyan type, with a fragment of the shark *Toxoprion,* or *Helicoprion.* Obviously it is of vital importance to discover more of this fossil fish material, and determine the exact horizon from which the one loose specimen so far found was derived.

Of much importance too is the further collecting and correlation of a Northern Hemisphere type of *Lepidodendron* flora, at Yarrada, near Derby, also in western Australia.

The brachiopods of the Kamílaroi of Western Australia offer a fine field for paleontological research, but unfortunately many of the best localities are difficult of access. Professor Schuchert has kindly offered to work at any of these brachiopods that can be obtained for him, and needless to say the cooperation of himself and of any other paleontologists or geologists from other countries, and, most of all, personal visits from them, would be warmly welcomed by their Australian colleagues.

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TERTIARY DEPOSITS OF WESTERN KENTUCKY[1]

BY JOSEPH K. ROBERTS

(Read before the Geological Society December 31, 1930)

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INTRODUCTION

This paper gives briefly some of the results of the field work in western Kentucky during the summer of 1929, and more briefly of that during the summer of 1926. The section covered is the extreme western portion of Kentucky, commonly known as the "Jackson Purchase Region." This region includes eight counties bounded by the Tennessee and Mississippi rivers on the east and west, respectively, by the Ohio River on the north, and by the Tennessee State line on the south. The region is a little more than 2,000 square miles in area, of which the Tertiary comprises approximately 75 per cent. The writer was assisted in the field work by Charles

[1] Published by permission of the State Geologist of Kentucky.
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W. Wilson of Princeton University. The collections of Wilcox and Jackson plants have been submitted for determination and description to Prof. E. W. Berry of Johns Hopkins University. Professor Berry has previously described a number of fossil floras of Tertiary age from this section.[2]

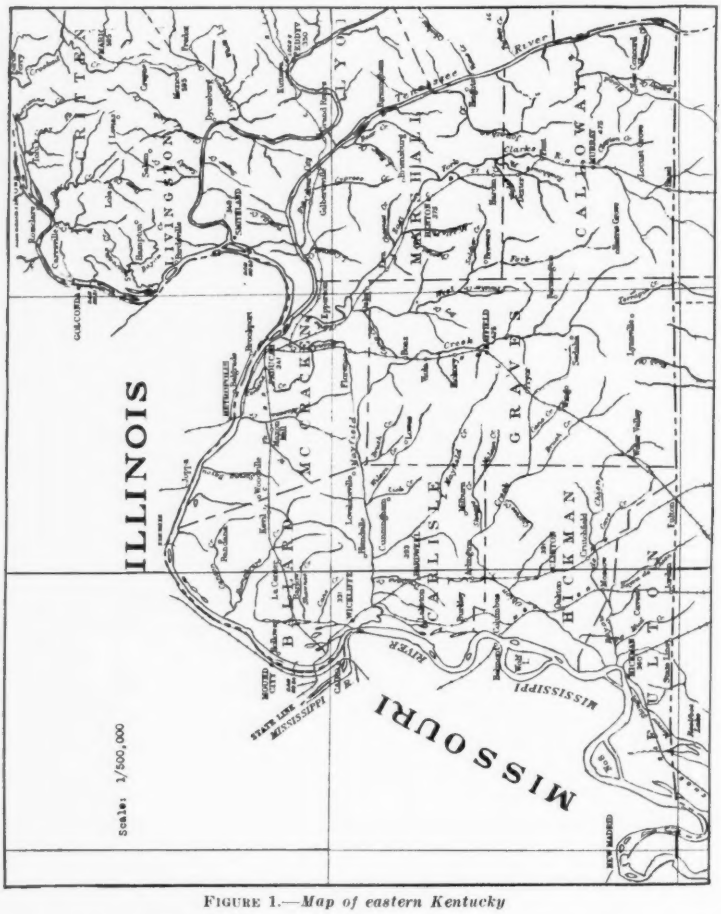

FIGURE 1.—*Map of eastern Kentucky*

Geologically, this region forms the northernmost part of the great embayment, and it differs in several respects from the region forming

[2] U. S. Geol. Survey, Prof. Papers, Nos. 91, 92, and 156.

the embayment farther south. The outstanding feature is the close similarity of the Holly Springs and Grenada formations, which necessitated mapping them together as the Wilcox.

The only extensive reports on this region are those of Loughridge,[3] Glenn,[4] and Berry.[5]

Numerous other papers have appeared from time to time on the economic geology, water supply, earthquakes, and general geology. The region has been of particular interest since the New Madrid earthquake, 1811-12. In the early days the region was visited by the geologists Owen, Lyell, and Lesquereux, who were especially interested in the geology shown along the Mississippi River bluffs. Similar regions to the south were studied nearly 75 years ago by Safford in Tennessee, and by Hilgard in Mississippi. Only in the last few years have some of the older formational units such as the Lafayette, Orange Sand, and Lagrange been restudied and replaced by other names largely through the studies of Berry, Cooke, and a few others.

Topography

Relief

The western two-thirds of the Jackson Purchase region is occupied by deposits of known Tertiary age, and consists of a more or less dissected peneplain. The Tertiary comprises parts of all eight counties; it appears in only the extreme western portions of Calloway, Marshall, and McCracken counties, but even the eastern portions of these three counties show Plio-Pleistocene deposits. Along the eastern contact of the Tertiary with the Upper Cretaceous a narrow ridge or upland section of country extends due north with an elevation of approximately 100 feet above the general level of the peneplain to the west. The peneplain region to the west occupied by the Tertiary has an average elevation of 375 to 400 feet above sealevel. Most of the region is swampy and rather flat, seldom varying more than 100 feet in elevation.

[3] R. H. Loughridge: Report on the geological and economic features of the Jackson Purchase Region, embracing the counties of Ballard, Calloway, Fulton, Graves, Hickman, McCracken, and Marshall. Kentucky Geol. Survey, Report F, 1888, 357 pp. 21 illus., 3 maps.

[4] L. C. Glenn: Underground waters of Tennessee and Kentucky west of the Tennessee River and of an adjacent area in Illinois. U. S. Geol. Survey, Water Supply Paper 164, 1906, 173 pp., 7 pls., 13 figs., 1 map.

[5] Edward W. Berry: The Mississippi River bluffs at Columbus and Hickman, Kentucky, and their fossil flora. Proc., U. S. Nat. Mus., vol. 48, 1915, pp. 293-303, 2 pls. The lower Eocene floras of southeastern North America. U. S. Geol. Survey, Prof. Paper 91, 1916, 481 pp., 65 pls., 9 figs. The Middle and Upper Eocene floras of southeastern North America. U. S. Geol. Survey, Prof. Paper 92, 1924, 199 pp., 65 pls., 9 figs. Revision of the Lower Eocene Wilcox floras of southeastern United States, with descriptions of new species chiefly from Tennessee and Kentucky. U. S. Geol. Survey, Prof. Paper, 156, 1930, 196 pp., 50 pls., 32 figs.

DRAINAGE

The main streams of the region are the Mississippi, Ohio, and Tennessee rivers. Most of the smaller streams are intermittent and take their source within the region. One stream, the Obion River, has some of its headwaters in Kentucky and flows through Tennessee into the Mississippi River. Few of the streams in this flat country have cut through and exposed the Wilcox and the Porters Creek formations. As pointed out by Glenn, artesian wells and small springs are numerous throughout the region. The divides are low and comparatively wide; one extends north, roughly paralleling the course of the Tennessee River, and the other, to the south, giving a radial pattern to the streams which take their sources near its highest points.

STRATIGRAPHY

GENERALIZED COLUMN

Geologic Column of the Jackson Purchase Region, Kentucky

Cenozoic	Quaternary	Recent alluvium
		Pleistocene loess and loam
	Tertiary	Plio-Pleistocene gravel and sand
		———Disconformity———
		Jackson formation—Upper Eocene
		———Disconformity———
		Grenada formation } Wilcox Group (Lower
		Holly Springs formation } Eocene)
		———Disconformity———
		Porters Creek clay—Midway Group (Lower Eocene)
		———Unconformity———
Mesozoic	Upper Cretaceous	Ripley formation
		———?Unconformity?———
		Eutaw formation
		Tuscaloosa gravel
		———Unconformity———
Paleozoic	Mississippian	Saint Louis limestone and chert

The stratigraphic section extends from the limestone and chert of Mississippian age through the unconsolidated gravel, sand, clay, thin beds of impure lignite, and loess of Upper Cretaceous, Tertiary, and Pleistocene to the Recent alluvial deposits. The geologic column for the region is even more fragmentary than it is to the south in Tennessee. The

Tertiary is represented in part by the Eocene, and in part by Plio-Pleistocene surficial deposits commonly known as Lafayette. The Midway is represented by the Porters Creek clay, and the Wilcox by the Holly Springs and Grenada, these three units constituting the lower Eocene. The middle Eocene or Claiborne is either absent, or overlapped. The upper Eocene is represented by the sand and clay of Jackson age.

MIDWAY GROUP

Representations in Kentucky and Tennessee.—In Kentucky the Midway group is represented only by the Porters Creek clay; in Tennessee it is represented by the Clayton formation and the Porters Creek clay. The former, older formation consisting of impure limestone and greensand is not found farther north than half-way between the Kentucky and Mississippi State lines in Tennessee, and it has not been observed anywhere in Kentucky. The Porters Creek clay extends as a narrow belt from the Tennessee line, and towards the Ohio River its aerial outcrops suggest a crescent-shaped pattern. Present knowledge does not permit it to be mapped as a continuous belt across the State.

Porters Creek clay.—The Porters Creek clay is a fine, smooth-textured clay, light gray when dry. It uniformly exhibits the same properties and is the most satisfactory of all the Tertiary units to map. It carries only a few indurated beds. When dry it breaks with a conchoidal fracture, and weathers into small blocks, a habit peculiar to it and, therefore, useful in its recognition. South of Paducah it shows a sand layer 1 to 2 feet thick at the top of the section, but just what part of the vertical range this is can not be determined, though it is believed to be near the top, if not the very top. The Porters Creek is the only truly marine formation in western Kentucky. It shows a few fish scales, and numerous casts of pelecypoda and gastropoda, the latter often too poorly preserved to permit of specific determinations. Thin layers not more than 6 inches thick of fine, angular sand occur interbedded with the clay in the sections exposed in Marshall County. At several points in Marshall County sand dikes occur in the Porters Creek, and the character of the sand closely resembles that of the thin beds in the clay. All the dikes observed are unconsolidated and consist of fine, angular, dark gray sand ranging in size from 100 to 200 mesh. Some of the dikes are as much as 18 inches wide. They form no symmetrical pattern, but extend in almost every direction. Neither in Kentucky nor in Tennessee have they been found cutting any beds younger or older than the Porters Creek clay. The clay beds have an apparent dip at low angles to the west, southwest, and

south in the lower, middle, and upper portions of the region, respectively. Recent reports from the Kentucky Geological Survey seem to indicate that this clay may be used in the laboratory as a substitute for Fuller's earth.

WILCOX GROUP

General statement.—The Holly Springs and Grenada formations have been mapped as one unit, for with the present information it is impossible to separate them. The Wilcox belt is widest on the Tennessee State line, and swings in an arcuate form to the northwestern corner of the region; at Wickliffe, Ballard County, it contains the best preserved fossil flora that has been collected anywhere throughout Kentucky.

Holly Springs formation.—The sediments that make up the Holly Springs comprise very small amounts of clay conglomerate, abundant sand and clay, the last composed in part of lignitic clay, that merges into a fairly good grade of lignite. The main thickness of sediments consists of sand with many lenses of clay. Most of the larger sand grains are well rounded quartz, with some feldspar and other minerals. Most of the sand is gray, but some of it is colored, and also is consolidated into thin layers by iron oxides. Fragments of silicified wood are found throughout the sand. By itself, the sand is distinguished only with difficulty from the Grenada, and in some places from the Plio-Pleistocene sand.

The Holly Springs clay varies considerably in color and composition. Some of it is smooth, white to light colored, and without grit; this variety is marketed as ball clay. Some of the white clay carries considerable amounts of grit, grading into sand. Some of the clay is yellow or brown, depending on the amount and kind of iron oxides it contains, or black to brown from its organic content. Bits of carbonized wood or plant fragments are commonly found in the clay, and many beds yield beautifully preserved leaves and a few fruits and flowers; fossil resin occurs in one of the clay pits.

Fossil floras from these beds of clay have been described by Lesquereux and Berry. The main plant localities are in Graves and Ballard counties, and perhaps the best of these for collecting is 1 mile west of Viola, Graves County, in the pit of the Kentucky Clay Mining Company. According to Berry, the known fossil flora of this pit represents 44 genera and 63 species. From Boaz Station 32 genera and 42 species are known, and from the Bell City Pottery near the Tennessee State line 20 genera and 21 species. Nearly 20 years ago collections were made by Berry from an indurated layer in the Holly Springs at the edge of the town of Wickliffe, Ballard County. In 1929 the writer collected a great many specimens,

representing 29 genera and 39 species from the clay pit, which has been in operation for some time on the southern edge of Wickliffe. Throughout the writer's field work only a few traces of faunas have been noted, but these have not been used in formational determinations.

Only certain kinds of clay contain leaves; none of the so-called white ball clays show traces of leaf imprints. Some of the very dark clays, colored by abundant and finely divided organic matter, contain a network of stems and leaves, but none of them are well enough preserved to be identified. High grade lignite up to 1½ feet in thickness occurs in the Holly Springs.

The floras collected by Loughridge, and determined by Lesquereux will not be listed in this paper, as they will be found reclassified by Berry in Professional Paper 91, pages 23-24. Berry also made certain collection from the embayment area in 1909 to 1913, which will be found in his publications referred to above. Only the plants which were collected by the writer in 1929 and determined by Berry will be listed below.

List of Holly Springs Fossil Flora from the Kentucky Clay Mining Company's Pit, One Mile East of Viola, Graves County, Kentucky

Anacardites puryearensis
Anona eolignitica
Apocynophyllum mississippiensis
Apocynophyllum mississippiensis ovatum
Apocynophyllum sapindifolium
Apocynophyllum wilcoxense
Banksia saffordi
Bombacites eocenicus
Canavalia acuminata
Capparis eocenica
Carapa eolignitica
Carpolithus puryearensis
Cassia emarginata
Cassia fayettensis
Cassia glenni
Cassia puryearensis
Cedrela mississippiensis
Cedrela odoratifolia
Cedrela puryearensis
Celastrus minor
Chrysobalanus inaequalis
Combretum wilcoxensis
Dalbergia wilcoxiana
Diospyros wilcoxiana
Dodonaea wilcoxiana
Dryophyllum puryearensis
Dryophyllum tennesseensis
Drypetes prelateriflora
Engelhardtia ettingshauseni
Ficus myrtifolius
Ficus pandurifolia
Ficus puryearensis
Ficus pseudopopulus
Ficus tennesseensis
Icacorea prepaniculata
Juglans occidentalis
Leguminosites andiraformis
Melastomites verus
Meniphylloides tennesseensis
Mespilodaphne coushatta
Mespilodaphne eolignitica
Metopium wilcoxiana
Mimusops sieberifolia
Myrica puryearensis
Nectandra parvula
Nectandra puryearensis
Nectandra pseudocoriacea
Nyssa wilcoxiana
Oreodaphne mississippiensis

Paraengelhardtia coccnica
Psychotria grandifolia
Reynosia praenuntia longepetiolata
Rhamnites knowltoni
Rhamnus coushatta
Sabalites grayanus
Sapindus coligniticus
Sapindus linearifolius
Sapindus mississippiensis
Sophora mucronata
Sophora repandifolia
Sophora wilcoxiana
Ternstroemites lanceolatus
Vantanea wilcoxiana
Folindusia sp.

List of Holly Springs Fossil Flora from Boaz Station, Abandoned Clay Pit, Graves County, Kentucky

Anona ampla
Apocynophyllum mississippiensis
Apocynophyllum sapindifolium
Artocarpoides wilcoxensis
Banksia saffordi
Canavalia eocenica
Carapa colignitica
Carpolithus burseraformis
Carpolithus gronori
Cassia fayettensis
Cassia purycarensis
Coccolobis colignitica
Cryptocarya wilcoxiana
Dillenites microdentatus
Diospyros wilcoxiana
Dryophyllum purycarensis
Dryophyllum tennesscensis
Engelhardtia ettingshauseni
Euonymus splendens
Ficus myrtifolius
Ficus pseudolmediafolia
Gleditsiophyllum eocenicum
Juglens schimperi
Laguncularia preraccmosa
Magnolia angustifolia
Mespilodaphne coushatta
Metopium wilcoxiana
Mimosites variabilis
Mimusops colignitica
Myrica elaeanoides?
Myrcia vera
Myrcia wortheni
Nectandra lancifolia
Nectandra purycarensis
Oreodaphne mississippiensis
Oreodaphne obtusiofolia
Poacites sp.
Sapindus formosus
Sapindus linearifolius
Schefflera formasa
Sideroxylon ellipticus
Sophora wilcoxiana

List of Holly Springs Fossil Flora from the Bell City Pottery Company Clay Pit, Collected by R. L. Collins and the Writer, Summer of 1926, *Graves County, Kentucky*

Anacardites metopifolia
Anacardites puryearensis
Anona robertsi
Apocynophyllum sapinifolium
Aralia? semina
Banksia tenuifolia
Bombacites cocenicus
Carpolithus kentuckyensis
Cassia purycarensis
Dryophyllum tennesscensis
Glyptostrobus europacus
Juglens schimperi
Nyssa wilcoxiana
Oreodaphne obtusifolia
Oreodaphne pseudoguianensis
Parrotia cuneata
Rubiacites sphericus
Sabalites grayanus
Sterculia knowltoni
Taxites sp.
Terminalia vera
Ternstroemites ovatus

List of Holly Springs Fossil Flora from the Lacleade-Christy Clay Pit, Wickliffe, Ballard County, Kentucky

Anona robertsi
Apocynophyllum mississippiensis
Banisteria pseudolaurifolia
Banksia saffordi
Bumelia wilcoxiana
Capparis eocenica
Carapa colignitica
Carpolithus fagaraformis
Cassia glenni
Cassia glenni major
Cassia puryearensis
Cedrela odoratifolia
Celastrocarpus eocenicus
Dalbergia eocenica
Dryophyllum puryearensis
Dryophyllum tennesseensis
Drypetes prelateriflora
Ficus puryearensis
Leguminosites drepanocarpoides
Magnolia angustifolia
Magnolia leci
Mespilodaphne colignitica
Mimosites lanceolatus
Mimosites variabilis
Mimusops coligniticus
Myrcia bentoncnsis
Myrcia wortheni
Nectandra pseudocoriacea
Nectandra wilcoxensis
Paleodendron americanum
Persea wilcoxiana
Poacites sp.
Reynosia praenuntia longepetiolata
Sabalites grayanus
Sapindus coligniticus
Sapindus formosus
Sapindus knowltoni
Sapindus linearifolius
Sapindus mississippiensis
Sophora mucronata
Small Unionidae and Folindusia

Grenada formation.—To the west of the known Holly Springs sand and clay are deposits which are very similar to the Holly Springs, as well as to the Grenada of Tennessee. These deposits consist of sand and clay, but show only a few traces of fossil plants. These beds are exposed in a few streams, and best in the new freight line cuts of the Illinois Central Railroad from Fulton, Kentucky, to Metropolis, Illinois. Their position suggests Grenada, as does also the fact that the clay carries small amounts of gypsum in the form of crystals. The top of most of the sections shows an erosional surface upon which lies the sand and gravel of Plio-Pleistocene age.

JACKSON DEPOSITS

The Jackson deposits have no aerial outcrops east of the Mississippi River bluffs, probably because they are covered by the Plio-Pleistocene deposits. The Jackson beds are found along the foot of the river bluffs, and well up the sides, and the outcrops are limited to Fulton, Hickman, and Carlisle counties. The clay forming the greater part of the Jackson is in a semiconsolidated state, in contrast with the older Tertiary clays to the east. Its general appearance at a distance is somewhat similar to that of beds of limestone. It is dove-colored when dry, is distinctly bedded, and has many joint planes. The clay contains small cavities, some of which bear a resemblance in form to plant stems, and fossil flora

have been collected from several localities. In 1919 Bruce Wade collected leaf impressions from Hickman and nearby points. During the summer of 1929, Mr. Wilson and the writer collected along the bluff 2½ miles south of Columbus, and this collection includes 10 genera and 11 species as determined by Professor Berry. All of the plants were collected from clay beds.

List of Jackson Fossil Flora from the Mississippi River Bluffs, Two and One-half Miles South of Columbus, Kentucky

Cassia cookfieldensis
Cedrela jacksoniana
Chrysophyllum precliriforme
Fagara catahoulensis major
Hicoria jacksoniana
Mimosites mississippiensis
Plancria hickmanensis
Sapotactites millicanensis
Sophora claiborniaia
Sophora wilcoxiana
Tecoma preradicans

The Jackson sand is medium gray, and has a distinctly finer texture than the sand of Wilcox age. The grains are sharp and angular, and its various properties are rather uniform. Fragments of carbonized wood occur through the sand layers but not to the extent that they do farther south at Robertson's Landing, Tennessee. No leaf impressions have been noted. The section at Columbus shows the sand discolored by iron oxides, and it is by no means the best section, although it is the one most commonly referred to in the literature. The sand occupies the basal portions and the clay the top of the sections.

PLIO-PLEISTOCENE DEPOSITS

In the past these gravel and sand deposits have been referred to as the Lafayette formation because of their lithologic resemblance to deposits in Lafayette County, Mississippi. These deposits form a blanket over most of the older formations of the Jackson Purchase region and are also found over the surface between the Tennessee and Cumberland rivers and far to the east of the latter river, in fact, as far east as Owensboro. Scarcely a section can be measured in the Tertiary of Kentucky or Tennessee in which these deposits are not included. The gravels consist of reworked chert, quartz, sandstone, quartzite, and occasional clay pellets. Many of the chert pebbles contained fragments of Lithostrotion corals, crinoid stems, bryozoa, and brachiopods. Most of the beds are unconsolidated, the gravels being in a loose sand matrix. In size the gravels average about 1 inch in diameter, though some are larger. The sand shows about the same composition as the gravel. The grains are well rounded, and usually coated with iron oxides, which in some places acts as a cement to form thin beds of conglomerate and sandstone. In color

these beds are reddish-brown with gray streaks. Everywhere the base of the deposits is an unconformity. The thickness varies up to as much as 30 feet; in many places the gravels are so thick that quarries have been operated in them to supply road material.

An interesting feature of the gravel and sand deposits is the inclusion in them of quartz boulders. These were mentioned by Loughridge,[6] though he apparently did not consider their possible significance; the writer's attention was first called to them by Dr. L. C. Glenn, whose view that they should be attributed to ice seems plausible. At present no other suggestions are offered. The largest boulders are found 2 miles north of Murray, Calloway County, where they were exposed by recent highway construction. Some of these boulders are estimated to weigh approximately 2 tons. At this locality they are flat, whereas in other places they are more nearly equidimensional. There are two other occurences, but the Murray locality is the most southern one. The quartzite of which these boulders are composed is light gray to white.

Conclusions

The Porters Creek clay is the most easily recognized of all the Tertiary formations because of its peculiar conchoidal fracture, its hackly nature, its color, texture, its position in the region, and its high degree of uniformity. Although its marine faunas readily indicate its stratigraphic position, their occurrence is not widespread enough to make them useful. The sand dikes are helpful in its recognition.

The Holly Springs is recognized by its flora, and by its type of sand; the habit of weathering in its clay beds distinguishes it from the Porters Creek.

The Grenada clay and sand beds are distinguishable only with difficulty so far north in the embayment; the clay carries some gypsum, whereas so far known to the writer the Holly Springs clay does not; but this is not yet a safe criterion. The Grenada sand is somewhat finer in texture than the Holly Springs but not as fine as the Jackson formation.

The Jackson beds can be differentiated from other nearby deposits through their fossil flora, peculiar induration of their clay, and the extreme fineness and uniformity of the sand.

The Plio-Pleistocene deposits may be recognized by their reddish-brown color, their uneven base, their habit of weathering, their widespread occurrence, their flattered gravels in contrast to the rounded Tuscaloosa gravels to the east, and by their reworked fossils.

[6] R. H. Loughridge: Op. cit., p. 60.

Geologic Column as used in the Jackson Purchase Region

Period	Loughridge, 1888	Glenn, 1906	Roberts, 1930
Quaternary	Alluvium and valley gravel	Alluvium	Alluvium
	Brown loam Loess	Loam member Loess member Sand member	Loess and loam
	Gravel beds and stratified drift: Stratified drift Gravel conglomerate Ore region gravel Tennessee River gravel	Lafayette formation	Plio-Pleistocene deposits
Tertiary	Hickman (lowest Eocene of Loughridge)	Lagrange formation	Jackson formation
	Lagrange (of Safford but does not include bluff lignite)		Grenada formation
			Holly Springs formation
	Lignitic (Safford's Porters Creek and bluff lignite)	Porters Creek clay	Porters Creek clay
Upper Cretaceous	Ripley formation—Cretaceous undifferentiated, sand toward south, and clay towards north	Ripley formation—Only Cretaceous member recognized	Ripley formation
			Eutaw formation
			Tuscaloosa gravel

Correlation of the Eocene of Kentucky with that of Tennessee, Mississippi and Alabama

Period		Kentucky (Roberts)	Tennessee (Roberts)	Mississippi (Cooke)	Alabama (Cooke)
Jackson group (Upper Eocene)		Jackson about equivalent to Tennessee	Jackson, L. Jackson, Crowley's Ridge	Jackson {Yazoo clay / Moodys marl	Jackson {Ocala limestone east of Tombigbee River
Claiborne Group (Middle Eocene)		Absent	Absent	Yegua formation	Gosport formation
				Lisbon {Koskiuski sand / Winona sand	Lisbon formation
				Tallahatta formation	Tallahatta formation
Lower Eocene	Wilcox group	Grenada formation	Grenada formation	Grenada formation Overlapped	Hatchitigbee formation
				Absent	Bashi formation
		Holly Springs formation	Holly Springs formation	Holly Springs formation	Tuscahoma formation
		Absent	Absent or overlapped	Akerman formation Overlapped	Nanafalia formation Overlapped
	Midway group	Porters Creek clay	Porters Creek clay	Tippah sand member / Unexplored area	Naheola formation
				Porters Creek clay	
		Absent	Clayton formation	Clayton formation	Clayton formation

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OUR YOUTHFUL SCENERY[1]

BY GEO. H. ASHLEY[2]

(Read before the Geological Society, December 31, 1930)

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INTRODUCTION

Were this a popular audience I should have illustrated my paper very fully. But geologists I am sure have mental pictures of most of the physiographic features referred to, so I have preferred to use no pictures lest they detract attention from the broader principles I wish to emphasize.

For the average man, New York harbor, the Mediterranean Sea or the Appalachian Mountains have always been and will always be just where and as they are now. That some geologists, even, hold that some of our scenery dates back little changed to Mesozoic or even Paleozoic time is shown by frequent references to the Cretaceous or Jurassic age of the highest Appalachian peneplain.

In contrast with both views I present the thesis that most of the world's scenery, its mountains, valleys, shores, lakes, rivers, waterfalls, cliffs, and canyons, are post-Miocene, that nearly all details have been carved since the emergence of man, and that few, if any, land surfaces today have any close relation to pre-Miocene surfaces.

[1] Manuscript received by the Secretary of the Society January 16, 1931.

[2] State Geologist of Pennsylvania.

To present the evidence in detail would fill a book. We must content ourselves with selected features which may be illustrative or typical. Indeed the purpose of my paper is not so much to cite specific instances of youthful scenery as it is to show that the instances cited are typical of widespread or general conditions.

Personal Observations

Following logical procedure by starting with what is nearest and most familiar, let us recall minor scenic changes all of us have witnessed. We have all observed how single storms or floods have materially changed the appearance of things at some particular point. It is sometimes said facetiously that the Niagara Falls our children see on their honeymoon is not the same falls we saw on ours, or that our grandparents saw on theirs. Indeed, we might picture Niagara at the cantilever bridge when Rome was founded. We have all noticed how quickly small mining operations in a hillslope are obliterated. I have personally noted several instances of 75-foot ravines cut within the 20 to 40 years preceding. You have doubtless seen coastlines that are obviously in retreat or river-cut banks that are changing under your very eyes.

Changes in historic Time

Multiply what we have seen and what others have seen or might have seen during 30 or 50 years by 100 or 200 and we realize what may have happened in the last 6,000 years, or during historic time. Geologically we know that many things have happened. Earthquakes have been accompanied by distinct uplifts or depressions. Volcanic eruptions, notably Skaptar in Iceland in 1783, have changed the appearance of large areas. Evidence is abundant that coasts are moving or have moved up and down during historic times; Scandinavia, Italy, Japan, our own Atlantic coast are examples. I mention these well-known phenomena merely to get our thinking started in terms of scenic changes.

Postglacial Changes

It is only a step from these historic changes to those admitted by all geologists to have taken place during or since the last advance of the continental glaciers. In this class obviously fall most of our small lakes, waterfalls, and many of our gorges within that advance, or mountain lakes, waterfalls, or ice-carved gorges or cirques of comparable age. Within the boundary of the Wisconsin (Laurentian or Würm) ice the whole aspect of the earth's surface has been transformed, partly by the

mantle of glacial drift in its many forms, partly by the lakes and swamps filling drainless basins, partly by postglacial gorges and waterfalls formed where drainage changes have occurred.

Not only is the surface within the Wisconsin boundary largely moulded by the drift and lake deposits of that and subsequent time, but in northern Ontario, for example, the whole rock surface gives evidence of having been leveled and smoothed by ice movement. It may not be possible to say just how much rock was removed, but a comparison of the sides of islands toward and away from the direction of motion of the ice suggests that the amount may have been hundreds of feet; certainly sufficient to have changed the whole complexion of the landscape.

To these changes must be added those resulting from differential earth movements, such as postglacial elevation of areas previously covered with ice, as in the Baltic area, around our Great Lakes, and elsewhere. The retreat of the ice left lower Manhattan under the sea and the Hudson and Saint Lawrence valleys a strait separating New England from the continent, much as Old England is still separated by the North Sea and English Channel.

Landscape making during the Pleistocene

Compared with these few thousands of years, Pleistocene time, corresponding to the Ice age as a whole, has been estimated to have covered several hundred thousand years, probably a million or more. Multiply what has obviously happened since the retreat of the ice by 25 or 50, and it is evident that a great deal may have happened during Pleistocene time. Imagine Niagara or Genesee gorges multiplied 25 or 50 times, and you will realize what might have happened during Pleistocene time.

Among features dating from Pleistocene time are the basins now occupied by the Great Lakes or the Finger Lakes of New York which were scooped out or deepened by ice during the Ice age. The Ohio and Missouri rivers of today are of post-Tertiary age. The valleys of central and eastern Pennsylvania show gravel-covered rock benches at 40 to 60 feet above the present streams. Leverett correlates these with the Illinoian advance of the ice estimated at about 150,000 years ago. In other words, the lower 40 to 60 feet of these valleys has been carved out of the rock since Illinoian time. What is true here is doubtless true elsewhere. Multiply that by 6 or 7 and it would appear that the lower 200 to 300 feet of these valleys has been carved during Pleistocene time. Indeed, in the Pittsburgh region there is no doubt that the valleys have been deepened 200 to 300 feet or more since the upper Ohio was deflected

from the Beaver Valley to its present course, possibly since Illinoian time.

Again, the world over, we find abundant evidence that most of what we call scenery dates from Pleistocene time. Whatever the time of their uplift the scenery of the Alps and other high mountains of the world today is ice carved. The spirelike Matterhorn, the vertical faces of Glacial National Park—all that makes these mountains scenic and picturesque are the faces of cirques, or as at Yosemite, ice-cut or ice-deeped valleys into which drop waterfalls— the Bridal Veil, the Staubach in Europe, the glens at Ithaca and Watkins. The Italian lakes and mountain lakes generally are obviously of very recent origin.

The Pacific coast is notable for changes that are certainly not older than the Quaternary and many of which appear to date from the last few thousand years. Judged by very recent deposits that have been depressed, uplifted, or folded, the whole coastal area has been and is being greatly changed. Raised beaches or wave-cut terraces to heights of 1,500 feet above sealevel tell of uplifts. In other areas depression has flooded valleys to produce San Francisco Bay, Merced Lake, and similar scenic features. So recent are some of these features that streams flowing across terraces have not had time to entrench themselves, but cascade directly into the surf over the face of a rapidly retreating sea-cliff.

Late Tertiary Scenery

Modern students of geology agree that although most of our highest mountains may have had one or more previous periods of folding, they reached their present elevations toward the end of Tertiary time. The Himalayas are said to have been folded first in the Cretaceous, again at the end of Eocene time, and still more at the end of Middle Miocene time. But it is said that their present elevation is due to subsequent uplift in Pliocene time. The Alps, after undergoing folding in late Paleozoic and late Cretaceous time, attained their greatest elevation in Pliocene time. A similar complicated history with late Tertiary uplift applies to the Caucasus, Apennines, Andes, Rocky Mountains, Sierra Nevadas, and Cascade ranges. It is said also that the plateaus of Utah and Arizona and the high plains of Colorado were elevated in Pliocene time.

A Study of the Yosemite

The United States Geological Survey published recently in Professional Paper 160 a detailed study of the Yosemite region by Francois E. Matthes that sets up standards of erosion correlated as to time that may serve as measuring rods in other regions. Tilting and partial uplift at the

end of Miocene time led to the cutting of a broad Pliocene valley seen now only in the high ridge lines. After a 6,000-foot uplift at the end of Pliocene time, the Merced River dug itself a V-shaped gorge 1,000 to 1,200 feet deep in the solid, massive granite. Then the ice took hold and is estimated to have deepened the valley by a maximum of 1,600 feet and to have cut even deeper into the flanks of the stream-cut valley to form the present U-shaped valley evidently carved during Pleistocene time.

The more the matter is studied the more it appears probable, if not certain, that all the highest parts of the earth's surface are high because elevation took place so recently that time has not sufficed for cutting them down. When, however, one notes how much of their present shapes is due to ice cutting during the Pleistocene time, one realizes that they probably antedate the Ice age very little.

Scenery of known Age the Key to other Scenery

All this is trite and not new. But while we all recognize these detached and obvious evidences of uplift and erosion how many of us fully evaluate and apply generally the rates of erosion expressed by these examples? It may not be possible to set the problem down and say: "Given a certain type and structure of rock, a stream of certain second-feet flow and initial fall, and there will result in a certain time a gorge of certain depth and cross-section." Nevertheless, the geologist who studies many such postglacial gorges, as at Niagara, along the Genesee, around Watkins or Ithaca, along the Delaware, and hundreds of others, or glacial valleys, such as the Allegheny, Ohio, or Yosemite, naturally associates any gorge of similar appearance anywhere with an age of equal shortness. When, therefore, we find a narrow gorge anywhere, are we not justified in asking ourselves, "Are there any conditions here that would render the cutting of this gorge slow, such as hardness of rock, smallness of stream, low gradient of flow?" Otherwise, are we not justified in assuming an age comparable with the age of the glacial or postglacial gorges I have mentioned? But gorges of this general type are found scattered all over the country and, I believe, must be set down as no older than the streams mentioned.

To explain these gorges outside the glacial boundaries, recent crustal movements must be postulated. To take a single example, north of the Delaware in the Philadelphia region, an upland having a general elevation of 300 to 500 feet above tide is intersected by narrow V-shaped ravines, typified by the well-known Wissahickon Creek Valley, having the earmarks of postglacial age, and seeming to bear evidence of very recent uplift in that area. It may be argued that the narrowness of these val-

leys, and of those of the lower Schuylkill and lower Susquehanna, is due to the hardness of the rock traversed. My contention is that if these stream gorges are compared with other gorges of known age, whether postglacial or glacial, some of which are cut in massive granite, it appears improbable that their age goes very far back into the Pleistocene, and less probable that it goes back into the Pliocene. Wissahickon Creek has a fall of almost 20 feet to the mile, and the lower Susquehanna of over 6 feet to the mile, a sufficient fall to give real cutting power.

Scenery where Time Markers are Lacking

I have now treated very briefly three broad areas of the earth's surface, and found everywhere evidence of youth. These include (*a*) the areas recently covered and modified by continental ice; (*b*) areas, especially along our seacoasts, modified by recent uplift or depression, and (*c*) areas of the high mountains admittedly uplifted in Pliocene times or since and carved into their present shape during Pleistocene time.

There remain great areas not covered by these three categories, especially in the interior of this and other continents, that are often, if not generally, classed as old, such as for example, most of subglacial Canada and New England, the Appalachian region, the part of the Mississippi Valley underlain by Paleozoic or even Mesozoic rocks, broad areas in our far west, and corresponding areas on other continents.

The very heart of my thesis is that while these areas may be underlain by old or even very old rocks, their present topography is very young, much of it as young as the types of topography already mentioned. Narrow valleys are hardly less abundant in these "old" areas than in the glaciated area, and indicate uplifts equally recent.

Let us start with the district east of the Mississippi. Obviously, most of this region had at some time been reduced nearly to a peneplain. At some time in the past, uplift set in, extending at least from central New York to Alabama. So far as can now be determined all of the present drainage dates from the beginning of that uplift, whether founded on an erosion surface or the surface of overlapping sea deposits. Last winter I presented before this Society evidence that the uplift dated from late Miocene time.

Since uplift started, several periods of standstill have occurred, during which new erosion plains developed. As conditions stand today the area consists of:

1. Unreduced residuals which antedate the late Miocene peneplain: Great Smoky and Black mountains, possibly the White Mountains.

2. Plateaus and mountain tops revealing the trace of a late Miocene peneplain (Kittatinny peneplain): Cumberland Plateau and highest mountain tops of most of Appalachian province, except as above, including probably the tops of the Adirondacks and Catskills, which give evidence of peneplanation.

3. Lower plateaus and ridge tops representing a long, later period of standstill: the valley uplands of eastern Pennsylvania, the plateaus and hilltops of western Pennsylvania, Ohio, Indiana, the Lexington plain of Kentucky, the Highland Rim of Tennessee. Locally this erosion plain lies 1,000 feet or more below the level of the Kittatinny peneplain.

4. Valleys and lowlands cut below the lower peneplain, comprising probably 90 to 95 per cent of the area.

Obviously, if the first uplift of the Kittatinny peneplain of which we have record began in late Miocene time all subsequent features are of later date. How much later depends in part on the date of the later and lower erosion plains.

I have shown that evidence in Pennsylvania points strongly toward the conclusion that the lower 200 or 300 feet of present valleys has been cut since early Pleistocene time. In southern Indiana and central Kentucky the hilltops are locally covered with a deposit of sand and gravel (my Ohio River formation, and the Irvine formation of Campbell). This appears to lie on top of the main secondary peneplain. Present stream valleys lie 400 feet and more below it. Leverett suggests that these deposits may be of early Pleistocene age. If so, 90 per cent of the present surface east of Mississippi River has been carved during the Ice age.

Recent work seems to show that there are two lower peneplains due to two periods of standstill. In places these nearly coincide, and elsewhere they may be several hundred feet apart. Both are included in Campbell's "Harrisburg peneplain." It now appears highly probable that the lower of these two plains is of early Pleistocene age, and that the higher plain is either early Pleistocene or late Pliocene. Either way it is obvious, assuming that I am right in my estimate of late Miocene age for the highest peneplain, that probably none of the surface of the United States east of the Mississippi River antedates Middle Miocene, 99 per cent of it is post-Miocene, and probably 90 per cent of it is post-Tertiary.

The drainage of this area is probably all post-Middle Miocene, and many of the present rivers, including the upper Tennessee River, flow in valleys excavated entirely since Middle Pliocene time. There is little doubt today that Cumberland and Big Sandy rivers originally rose in

North Carolina and have been decapitated by the Tennessee. Quartzite boulders, thought to be Hesse quartzite from North Carolina, are reported by Jillson as found on the hills along the middle part of Big Sandy River Valley, and at levels that would show them to be younger than the laying down of the Irvine formation of Campbell.[3]

Nor is evidence lacking that all of this great area has shared with the coastal region in recent crustal movements. A single example is the evidence of recent subsidence in western Kentucky, covering 4,700 square miles, and in southwestern Indiana, where the valleys are filled to a depth of 100 to 200 feet and a width of 1 to 8 miles. East of this is a broad area that has been recently uplifted, followed by the cutting of deep, narrow valleys, as illustrated by the lower course of Blue River in Indiana. The upper valleys are shallow depressions in a rolling upland, while the lower river runs in a narrow gorge, several hundred feet deep.

What is true east of the Mississippi River, is equally true west of the river, as will be evident if one recalls that late Teritary sediments still mantle hilltops in western Oklahoma; that Miocene lake beds or lavas cap high places throughout the Great Plains area; that the Columbia Plateau is formed by Miocene or later lavas; that the Brown's Park beds of Utah of Miocene or later age are antecedent to the cutting of the Lodore and other canyons of the Southwest. An excellent example of the extent of recent erosion is found in the lava-capped divides of the Sierras, below which the American River has cut 2,000-foot canyons (3,000 feet below the old divides).

What is true of the supposed older parts of North America appears to be equally true of the supposed older parts of other continents. One has only to recall how short a time ago the Rhine flowed southward into a gulf at Maintz, or that according to Lawson and Breasted, primitive man watched the Nile first threading its way down the valley it now occupies. That is too long a story, however, to tell here.

Our information may not be complete enough to enable us to make relief maps or models of the earth's surface at various times since the close of Oligocene time. Nevertheless, I hope that what I have said will lead some geologists to study more thoroughly the age of some of our physiographic features.

Corollaries and Conclusions

A corollary of my thesis might be: No part of the earth's crust, if continuously subject to active erosion, can maintain its integrity longer

[3] W. R. Jillson: Topography of Kentucky, 1927, p. 241.

than one geologic period. By geologic period I refer here to the modern definition of periods, by which the Tertiary and Cretaceous are divided in two each, and the Carboniferous into three periods.

If my thesis and its corollary are correct, it follows (using the eastern United States as an illustration): (*a*) That the Greak Smoky and Black mountains at the south, the White, Adirondack, and Catskill mountains at the north, all date from uplifts since the beginning of Miocene time, and that the lower surfaces, 99 per cent of the whole area, date from still later time. If true of the eastern United States it is assumed to be true elsewhere; (*b*) the mantle of rock removed from below the tops of the mountains named is a partial measure of the erosion since early Miocene time; (*c*) the Permian strata remaining in southwestern Pennsylvania and West Virginia are only a partial measure of the Permian and possibly later rocks originally deposited in the eastern United States.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PERMIAN VERTEBRATE TRACKS IN WEST VIRGINIA[1]

BY JOHN L. TILTON[2]

(Read before the Paleontological Society December 31, 1930)

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Dimetrodon berea, New Species

The tracks (figure 1, A) are in Waynesburg sandstone obtained 0.4 mile southwest of bridge over Hughes River at Berea, Ritchie County, West Virginia. They were exposed during road work in the summer of 1927. They were cared for by Mr. David H. Jones of Berea till August, 1929, when, on solicitation by Mr. David B. Reger and the writer, they were placed in the museum of West Virginia University (Permian Number 182).

The ledge from which the specimen came is illustrated by figure 2 of the Waynesburg sandstone, though the exact layer from which it came could not be ascertained. The position of this bed among others is stated in the accompanying section which was made in the locality by Mr. David B. Reger.

Berea Section

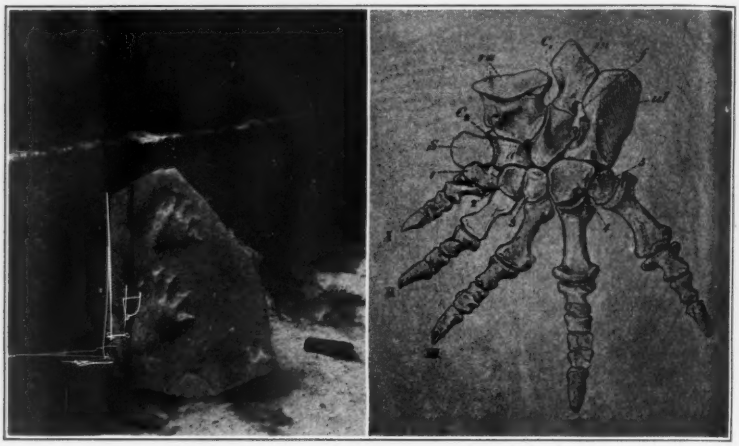
This section was made at Berea, Ritchie County, West Virginia. It was measured with hand-level by David B. Reger, and is arranged in descending stratigraphic order. It starts at the top of a high point 0.5

[1] Published with permission of the West Virginia Geological Survey.

The writer wishes to acknowledge the kindness of Dr. C. W. Gilmore of the U. S. National Museum, whose work on the fossil footprints from the Grand Canyon is well known. Dr. Gilmore kindly exhibited the collection to the writer, loaned him the original drawing of the foot of *Dimetrodon gigas*, which is here reproduced, and reviewed the paper.

Manuscript received by the Secretary of the Society, February 24, 1931.

[2] As Professor Tilton died of a heart attack in the classroom November 17, 1930, his paper was read by Dr. S. L. Galpin.



A B

FIGURE 1.—*Illustrations of Dimetrodon*

A, Tracks of *Dimetrodon berea* as photographed by the roadside at Berea, August, 1929. The rule is two feet long.

B, Left forefoot of *Dimetrodon gigas* Cope illustrated by Dr. C. W. Gilmore in the Proceedings of the U. S. National Museum, volume 56, 1920, figure 8, page 537. C_1C_2, Centrale 1 and 2; *f*, intra-carpal foramen; *in.*, intermedium; *ra*, radiale; *s*, sesamoid; *ul*, ulnare; *1*, *2*, *3*, *4* and *5*, carpals 1-5; *I*, *II*, *III*, *IV*, *V*, digits 1 to 5.

Photograph by John L. Tilton.

FIGURE 2.—*Location where tracks of Dimetrodon berea were found*

The Waynesburg sandstone is exposed in road cut at bend in road 0.4 mile southwest of the bridge at Berea. Photograph by John L. Tilton.

mile west of Berea and just north of the road summit and thence extends southward with the public road to the South Fork of Hughes River at the road fork 0.5 mile southwest of Berea.

	Thickness (feet)	Total (feet)
Permian System—Dunkard Series (327′ +)		
1. ***Sandstone, Hundred***, greenish-brown, partly concealed in steep bluff (1,085′ B)	45	45
2. Shale, red, partly concealed to road summit	33	78
3. Shale, red, slightly calcareous	11	89
4. ***Sandstone, Upper Marietta***, green, very shaly, with abundant red shale	27	116
5. Shale, red	6	122
6. Fire clay shale, *Washington "A" Coal* horizon (1,007′ B)	1	123
7. ***Shale, Creston***, red	33	156
8. ***Sandstone, Lower Marietta***, green, very shaly	13	169
9. Shale, red and yellow	19	188
10. Slate, dark	1	189
11. ***Coal, Washington*** (2′ 0″) very slaty at road outcrop (939′ B)	2	191
12. ***Fire Clay Shale, Washington***, yellowish-green, tinged with red at base	23	214
13. ***Sandstone, Mannington***, green, micaceous, very shaly, with streaks of red shale and slightly calcareous at top	23	237
14. Shale, red and sandy	4	241
15. Shale, dark, carbonaceous, *Waynesburg "A" Coal* horizon (888′ B)	1	242
16. Shale, red and green, with sandy streaks	26	268
17. Sandstone, greenish-gray, very shaly 19′		
18. Shale, red, with dark streak near top 8		
19. Shale, green 2		
20. Sandstone, greenish-brown, micaceous, medium-coarse massive at top and bottom but flaggy in middle, with a little shaly conglomerate at base, with foot-prints on a flagstone near base 30		
Waynesburg Sandstone (803′ B)	59	327
Pennsylvanian System—Monongahela Series (65′ +)		
21. Shale, mostly red, but partly green, with a few limestone nodules and lenses of sandstone	41	368
22. ***Sandstone, Uniontown***, green, flaggy and shaly and partly concealed to South Fork of Hughes River (740′ B)	22	390

The slab is 63.5 centimeters (25 inches) long, 48 centimeters (19 inches) wide and 7 centimeters (2.75 inches) thick, composed of greenish and gray medium-grained sandstone. The imprints are obverse (negative) in character; that is, formed of sand deposited later in the foot impressions that had been made. The material beneath on which the animal walked is not present but the character of the material in the hillside indicates that it is of the same general character as that of the slab itself. The surface is pitted with raindrop impressions visible over the entire surface excepting where material is scaled off. The stone parted nicely along the contact of the old surface with the overlying sand.

As the impressions are obverse (negative) the two longest impressions are evidently of the right feet, the first digit and toe extending out nearly at right angles to the general axis of the impression. The upper one in the picture (figure 1) is considered the impression of a fore foot, and the lower and larger impression the impression of a hind foot. This lower impression reaches farther back toward the heel than the impression of the fore foot. The distance between these two impressions is 5.5 centimeters (2.2 inches). The measurement from the posterior point of each impression to the tip of each impression of a toe is as follows:

MEASUREMENTS OF *DIMETRODON BEREA*

	Hind foot cm.	Fore foot cm.
To the end of the first digit	19.5	13.5
To the end of the second digit	22.5	15.5
To the end of the third digit	24.2	16.5
To the end of the fourth digit	24.8	18.0
To the end of the fifth digit	20.5	[2] 13.5

The lengths of the digits are as follows:

	Hind foot cm.	Fore foot cm.
First digit	5.5	6.0
Second digit	6.0	6.5
Third digit	8.0	8.0
Fourth digit	8.5	8.5
Fifth digit	6.5	6.5
Width of impression at base of digits	12.0	12.0

The sideways movement of the claws has affected somewhat the measurements of the length.

[2] Incomplete.

Fourteen centimeters (5.5 inches) off to the right is the edge of another impression, 32 centimeters (12.6 inches) from axial line to axial line, as if made by a foot on the opposite side of the body, and between these two is another smaller impression made by another smaller animal, which is not so distinct as the main impressions. This small imprint is but 10 centimeters (3.9 inches) long and 5.5 centimeters (2.1 inches) wide with marks preserved of only four of the toes.

The twisted and knotty appearance in the large tracks suggests that as the animal walked the toes moved slightly sideways (outwards). To make an impression in such material would require considerable weight, for the impression of the fore foot is 3.5 millimeters (0.1 inch) deep, deepest at the outside of the track; the impression of the hind foot is 1.3 millimeters deep and is even in character. Furthermore, the outward push is evident in the upward swelling as of wet sand at the outside of the impression of the fore foot.

The downward pressure of the foot indicates that the animal stood up well from the ground, though the impression of the hind foot makes it evident that the animal was not long-legged. This judgment is sustained by the total absence of a body mark. There is no trace of a tail. The fourth toe of each foot is the longest, and evidence of the presence of claws is distinct.

The tracks found at Berea as above described are unlike any seen in the collection from the Grand Canyon, but they are of a type such as *Dimetrodon* would make, as judged from the mounted specimen of this reptile in the U. S. National Museum. It is therefore proposed to name the specimen *Dimetrodon berea,* the specific name referring to locality where the specimen was obtained. As the *Dimetrodon gigas* in the National Museum is from the Permian of Texas and *Dimetrodon berea* is from the Waynesburg sandstone of the Permian in West Virginia there is this much of evidence to indicate that beds in the two regions are of the same age.

Baropus waynesburgensis, New Species

The footprint[4] illustrated in figure 3 came from 19½ feet below the top of the Waynesburg sandstone and 13 feet above the creek bed at a point 5.7 miles northwest, down Middle Island Creek, from the nearest

[4] The tracks were discovered August 17, 1925, by Harold Riggs while removing stone in grading the road. Mr. Riggs states that the slab before it was broken had seven prints on one side and five prints on the other of the trail, and that the two lines were a foot apart, with a stride of 18 inches from a print on one side to the next similar print on the same side. The slab was later broken in pieces by the workmen.

bridge at West Union, Doddridge County, West Virginia. Where the Elm Grove limestone (0-2 feet) is absent the Waynesburg sandstone comes down next above the Cassville shale, the bottom of which is generally called the base of the Permian, though Permian conditions are evident far down in the Conemaugh Series.

The footprint here illustrated was made in a thin layer of mud that covered a coarser, but still fine, micaceous sandstone. The surface is

FIGURE 3.—*Locality where Baropus waynesburgensis was found*

The tracks were found in the Waynesburg sandstone (at the base of Dunkard, Permian) at the level of the man's hand in the picture. The location is at a bluff along Middle Island Creek at a distance of 5.7 miles northwest of West Union, West Virginia.

somewhat mottled, as if a slight shower had occurred after the prints were made and the water had nearly obliterated the raindrop impressions. The bottom of the slab is strongly ripple-marked.

The illustration (figure 4) is that of a left fore foot and of a left hind foot. The impression of the fore foot reveals four digits, distal part deeply impressed, carpal portion less distinctly outlined. The impressions of the second and third digits are inclined, as if pressure were exerted toward the left, pushing the mud slightly that way. The first (right) impression of a digit leads directly from the left (direction), as if the radius and ulna were directed somewhat inward distally. The length of the first toe is 20 millimeters, the second 30 millimeters, the third 35 millimeters, and the fourth (left) 25 millimeters, measured from the tip back to end of impression between the toes. For the hind

foot the length of impressions, measured in a similar manner, are (right) 22, 43, 45 and 30 millimeters (left).

The impressions do not seem to be those of *Allopus*,[5] for *Allopus* is described as having five toes on the fore foot with the third toe the largest. Neither are they like those of *Nanopus*,[6] for, regardless of size, the order for length of toes of the hind foot is not the same. The imprints are like

FIGURE 4.—*Baropus waynesburgensis*

This specimen was taken from the Waynesburg sandstone (at the base of the Dunkard, Permian) in a bluff along Middle Island Creek at a distance of 5.7 miles north-west of West Union, West Virginia. This is one of five specimens in the geological collection at West Virginia University (*A* of Permian Number 8).

those of *Baropus*.[7] The specimens here illustrated are therefore considered to be footprints of *Baropus* Marsh.

As to whether these specimens represent a different species than that found in Arizona the judgment must depend on the measurements. The Arizona animal is described as climbing a slope of wet, cross-bedded sand.[8] The West Virginia animal was walking on a flat. The Arizona animal placed his hind foot before the impression of his fore foot as he

[5] O. C. Marsh: Footprints of vertebrates in the Coal measures of Kansas. Am. J. Sci. (3), vol. 48, 1894, p. 83. See also C. W. Gilmore: Fossil footprints from the Grand Canyon. Smith. Misc. Col., vol. 77, no. 9, 1924, pp. 29-31.

[6] O. C. Marsh: Idem.

[7] O. C. Marsh: Idem. See, also, C. W. Gilmore: Fossil footprints from the Grand Canyon: Second Contribution. Smith. Misc. Col., vol. 80, no. 3, 1927, p. 24.

[8] C. W. Gilmore: Fossil footprints from the Grand Canyon: Second Contribution. Smith. Misc. Col., vol. 80, no. 3, 1927, pp. 23-26.

went up the slope, and crowded the sand backward. The West Virginia animal was walking leisurely on a flat and crowded the wet sand out laterally somewhat as he progressed. He did not place his hind foot before the impression of his fore foot.

Such measurements as can be made are as follows:

	Baropus coconinoensis, Arizona mm.	*Baropus waynesburgensis*, West Virginia mm.
Length of stride	300	457 [9]
Width of tracking		305 [9]
Length of impression:		
Fore foot	75	...
Hind foot	108	100
Breadth of impression:		
Fore foot	100	115
Hind foot	138	120
Length of toes:		
Fore foot, I.		20
II.		30
III.		35
IV.		25
Length of toes:		
Hind foot, I.	30	22
II.	30	43
III.	35	45
IV.	35	30

Even allowing for variations due to conditions under which the imprints were made, and recognizing that specimens from places so far apart as Arizona and West Virginia may yet (in Permian times) have had the same species, it does not seem to the writer that the similarities are such that the imprints should be referred to the same species. He therefore proposes the specific name *waynesburgensis*, referring to the formation from which the specimen came.[9]

Neither can the specimen be considered of the same species as *Baropus lentus* Marsh, for Marsh states that, "On the inner side of each foot, however, there was a projection which in the hind feet was quite prominent

[9] As estimated by Mr. Harold Riggs, as stated on page 386 of the Bulletin of the Geological Society of America, volume 37, 1926, page 386. The same report tells of the conditions under which the specimen here named was found and describes other specimens that were found with it. The description of slab A is here repeated that description and illustration may accompany the proposal of a name.

and characteristic."[10] There is no evidence of such a projection in the tracks found in West Vriginia.

The generic name *Baropus* was proposed by O. C. Marsh in 1894 in an article entitled, "Footprints of Vertebrata in the Coal Measures of Kansas."[11] As *Baropus waynesburgensis* is from the base of the Permian of West Virginia and *Baropus coconinoensis* is from the Coconino sandstone of the Grand Canyon, there is this much to indicate correlation between these two beds.[12] In the above description of tracks of *Dimetrodon berea* from the Waynesburg of West Virginia and reference to *D. gigas* from the Permian of Texas, it is also noted that they served as somewhat of evidence toward the correlation of the beds in Texas[13] with the Waynesburg Sandstone of West Virginia.

[10] O. C. Marsh: Footprints of vertebrates in the coal measures of Kansas. Am. J. of Sci. (3), vol. 48, 1893, p. 83.

[11] Idem.

[12] *Baropus lentus* Marsh is by Gilmore referred to the Pennsylvanian of Kansas. Fossil footprints from the Grand Canyon: Second Contribution. Smith. Misc. Col., vol. 80, no. 3, 1927, p. 10.

[13] Roy L. Moodie: Vertebrate footprints from the Red-Beds of Texas. II. Journ. of Geology, vol. 38, 1930, p. 548. This paper describes and illustrates other genera that also are of value in correlation. Part I preceding this paper is entitled Vertebrate footprints from Texas Red Beds. Am. Journ. of Sci., vol. xvii, 1929, pp. 352-368. Neither of these papers describe forms like the two here described.

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SEA-BOTTOM SAMPLES FROM THE CABOT STRAIT EARTHQUAKE ZONE[1]

BY E. M. KINDLE[2]

(Read before the Geological Society December 31, 1930)

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INTRODUCTION

The bottom samples discussed in this paper represent 24 stations in the region southwest of the Grand Banks where many cable breaks were caused by the earthquake of November 18, 1929. These samples were obtained by the cable repair ships, the *John W. Mackay* and the *Faraday;* 17 were sent to me by Mr. A. E. Powell, vice-president of the Commercial Cable Company, and I am indebted to Prof. D. S. McIntosh, of Dalhousie University, Halifax, Nova Scotia, for the opportunity of studying five others.

All the sediments included in this study fall in the class of terriginous deep-sea deposits, coming from depths ranging from 400 to 2,000 fathoms. The fact that 12 cables were broken, some of them in many places, by the heavy earthquake of November, 1929 (figure 1), lends especial interest to the samples of sediment forming the sea-bottom on which this havoc was wrought.

The samples recovered are specimens caught in crannies of the grapnels

[1] Published with permission of the Director, Geological Survey of Canada, Ottawa.
[2] Manuscript received by the Secretary of the Society January 19, 1931.

and towing gear in the course of repairing the cables. So far as the cables lying in the region of the earthquake are concerned, the broken speci-

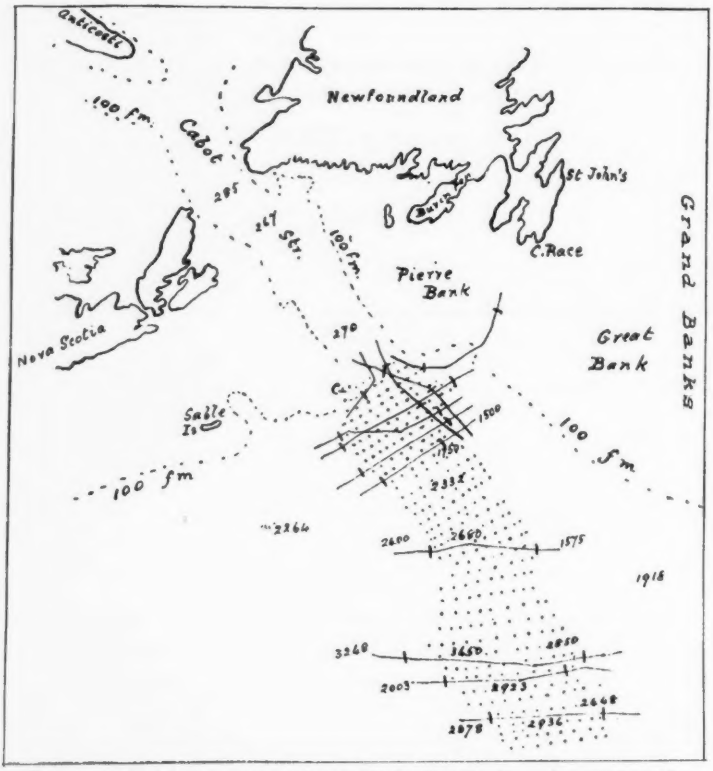

FIGURE 1.—*Sketch Map of the Cabot Strait Earthquake, November 18-19, 1929*

The thin lines represent the 12 broken cables; the cross bars the approximate positions of 23 fractures.

The dotted area represents the probable foundered band in continuation of the Cabot Strait.

Approximate position of the *Caledonia* when violently shaken by the earthquake.

The devastation on the coast of Newfoundland was mainly near the Burin Peninsula.

Depths in fathoms.—From J. W. Gregory.

mens recovered show clean surfaces at the breaks; there is no rust or growth upon them, showing that the fractures were brought about by physical strain and not by chemical corrosion.[3]

[3] Personal communication from A. E. Powell, vice-president, Commercial Cable Company.

In the study of the bottom samples the writer has been favored with cooperation of other students of the physical and biological features of sediments, and he wishes to acknowledge his indebtedness to Mr. F. J. Fraser, Dr. Albert Mann, Dr. Joseph A. Cushman, Prof. H. A. Pilsbry, Dr. Parker D. Trask and Mr. R. T. C. Fabry.

Macroscopic Characteristics

The macroscopic features of the samples are briefly indicated below:

Number 1.—Mottled brown-and-gray clay with pebbles resembling those from till. Depth, 1,600 fathoms; latitude 43° 57′ north, longitude 56° 55′ west.

Number 2.—Fine-textured brown clay with an angular pebble 40 millimeters in length. Depth, 1,500 fathoms; latitude 44° north, longitude 56° 37′ west.

Number 3.—Gray clay with quartz sandstone and other kinds of pebbles similar to glacial till pebbles. Depth, 1,550 fathoms; latitude 44° north, longitude 56° 33′ west.

Number 4.—Mottled dull brownish and gray clay; minute mica flakes abundant. Depth, 1,375 fathoms; latitude 44° 32′ north, longitude 55° 1′ west.

Number 5.—Mottled gray-and-brown clay with worn pebbles up to 25 millimeters in length. Depth, 1,600 fathoms; latitude, 43° 58′ north, longitude 56° 55′ west.

Number 6.—Laminated lead-gray and ash-gray clay, the latter much more sandy than the former. The single dark lead-gray band preserved in the lighter colored clay has a thickness of 2 to 3 millimeters. Depth, 1,100 fathoms; latitude 44° 36′ north, longitude 54° 55′ west.

Number 7.—Dull brown pebbly clay with small patches of bright red clay. Granite and other pebbles up to diameter of 20 millimeters present. Depth, 1,650 fathoms; latitude 44° 13′ north, longitude 55° 50′ west.

Number 8.—Sandy clay, mottled brown and gray, probably representing clay in red and brown layers. Depth, 1,650 fathoms; latitude 44° 8′ north, longitude 56° 2′ west.

Number 10.—Fine-textured brown clay. Depth, 1,600 fathoms; latitude 44° 7′ north, longitude 56° 7′ west.

Number 11.—Fine-textured brick-red clay. Depth, 1,700 fathoms; latitude 43° 50′ north, longitude 57° 12′ west.

Number 13.—Resembling typical gray glacial till with pebbles up to 35 millimeters in length; one striated. Depth, 400 fathoms; latitude 44° 45′ north, longitude 56° 9′ west.

Number 14.—Till-like with small, ice-scratched pebbles; gray with a trace of brown. Depth, 400 fathoms; latitude 44° 45′ north, longitude 56° 9′ west.

Number 15.—Brick-red clay with pebbles up to 50 millimeters in length; some with striæ. Depth, 505 fathoms; latitude 44° 45′ north, longitude 56° 15′ west.

Number 16.—Brownish clay with worn and rounded pebbles and thin sheets of dark red sandstone 60 millimeters across. Depth, 450 fathoms; latitude 44° 42′ north, longitude 56° 18′ west.

Number 17.—Reddish-brown clay with numerous small pebbles mostly 3 millimeters or less in diameter, some showing traces of striæ. Depth, 1,850 fathoms; latitude 43° 34′ north, longitude 57° 24′ west.

A. Bluish-gray clay effervescing freely (estimated)....50 per cent
Subangular pebbles ¼ to 1 inch in diameter, mostly limestone .....50 per cent

B. Silty brownish-gray sediment (estimated).....80 per cent
Pebbles 1/16 to ½ inch in diameter, mostly quite small approaching coarse sand in size (estimated).....20 per cent

C. Fine-textured brownish clay with abundance of minute flakes of mica. Latitude 42° 30′ north, longitude 56° 20′ west.

D. Coarse-textured gray clays with numerous pebbles or coarse sand grains averaging 2½ millimeters in diameter. One rounded pebble 8 millimeters in length. Depth, 950 fathoms; latitude 44° 47′ 56″ north, longitude 56° 10′ 30″ west.

E. Brown clay with pebbles 5 millimeters and smaller in diameter. Depth, 2,000 fathoms; latitude 43° 52′ 30″ north, longitude 54° 68′ 12″ west.

The location of sample stations and depths of adjacent parts of the sea are shown by the map, figure 2.

Mechanical Analysis and petrographic Description

Seven samples representing the finest-textured sediments in the collection were selected for examination as to their mineral composition and the proportion of sand, silt and clay present in them. The report on these by Mr. F. J. Fraser follows:

Samples were left in 2 per cent sodium carbonate solution for 24 hours and then boiled for 2 minutes. The red clays gave a fine suspension which stands for at least several days. The suspension was decanted off so as to make a rough separation of any sand and coarse mate-

rial. Residual material was dried and shaken on a sieve of 0.1-millimeter openings, the finer material passing through being ultimately added to the silt grade. The decanted material was elutriated so that material finer than 0.01 millimeter was washed away, leaving silt as a residue. As the material contained organic remains, sieving was avoided except as noted above. The silt grade thus obtained, therefore, contains many

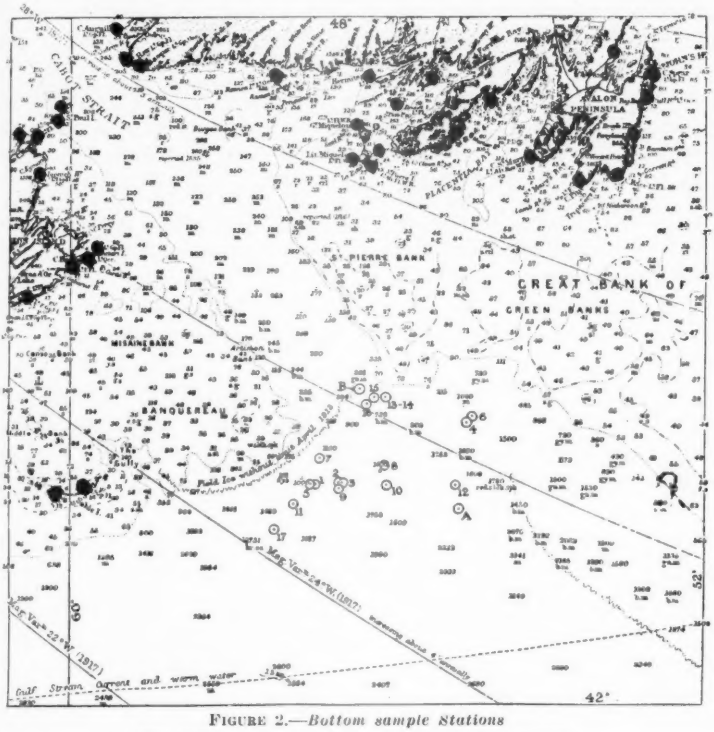

FIGURE 2.—*Bottom sample Stations*
The stations are indicated by circles with dot centers.

foraminifera which would otherwise be sieved off with the sand grade; the error thus introduced into the weights of the final products is, however, so small that it may be neglected in the calculation of the relative proportions of sand, silt and clay. The pebble and sand content of the samples is so small that both are included under the heading "sand."

For the present investigation, "sand" is all material retained on a sieve having openings of 0.1 millimeter; "silt" is material composed of particles

finer than 0.1 millimeter and greater than 0.01 millimeter; "clay" is all material composed of particles finer than 0.01 millimeter. The relative proportions of these are shown in table below:[4]

Sample number	Latitude	Longitude	Depth (fathoms)	Composition		
				Sand Per cent	Silt Per cent	Clay Per cent
2	44°N.	56°37′W.	1,500	1	14	85
4	44°32′N.	55°01′W.	1,700	10	32	58
8	44°08′N.	56°02′W.	1,650	2	38	60
9	43°59′N.	56°39′W.	1,530	.....	29	71
10	44°07′N.	56°07′W.	1,600	1	33	66
*11	43°50′N.	57°12′W.	1,700	.....	.....	.....

*After removal of 63 per cent of clay by elutriation residue is slightly calcareous.

All samples contain foraminifera and numbers 9 and 12 contain diatoms. All samples are essentially clays, and contain carbonates. Treatment with cold acid has little or no visible effect, but on warming, a brisk effervescence is produced. The carbonates are, therefore, probably dolomite.

Of the heavy mineral content, green hornblende is by far the most important; all the grains are very fresh, and many of them show good pleochroism. Apatite is next in importance in nearly all samples, sometimes showing good faces. Pink or colorless garnet is third in importance. Zircon was noted in all but one sample, but is not common. Tourmaline was noted in five samples, but may be considered rare. Rutile and hypersthene each were noted in one sample, hypersthene being recognized by its pink-to-green pleochroism. A few epidote and hypersthene grains complete the list of nonopaque, heavy minerals identified.

[4] For number 2 analysis 15.8 grams were examined.
For number 4 analysis 26.3 grams were examined.
For number 9 analysis 18.1 grams were examined.
For number 10 analysis 39.7 grams were examined.
For number 11 analysis 12. grams were examined.
For number 12 analysis 7. grams were examined.

Sand portion of number 2 contains rock fragments up to 5 millimeters in length. Most of these are dark and fine-grained and of a cherty character, but a few are greenish or red schistose fragments. Some of the quartz grains are well rounded and angular. The remainder of the sand portion is made up of rusty debris and a small amount of shell fragments, with a few foraminifera. Silt portion contains an appreciable amount of carbonate. Under the microscope, the carbonate is seen as rectangular or roughly prismatic grains, or as irregular aggregates suggesting comminuted shell fragments; cleavage rhombs are common. Quartz and feldspars make up the bulk of the material; plagioclase is rare. Some of the grains are probably of a cherty nature. Mica flakes about 0.04 millimeter across are fairly common, muscovite being more frequent than biotite; the latter is greenish or more often brown. Hornblende, apatite, tourmaline and garnet are present. The silt grains are uniformly 0.02 to 0.03 millimeter in diameter, rarely exceeding 0.04 millimeter.

A concentrate from the original sample yielded a very small amount of heavy minerals, and calls for little comment. Hornblende is the most common mineral.

Sand portion of number 4 contains a few rock fragments up to 5 millimeters in length. Well-rounded and etched grains of quartz are about equal in amount to small angular grains of the order of 0.1 millimeter in diameter. There is an occasional grain of glauconite and many foraminifera.[5]

Silt portion contains a small amount of carbonate. Under the microscope very few grains are seen that exceed 0.05 millimeter in diameter; most of them are between 0.01 and 0.05 millimeter. Occasional muscovite flakes, plagioclase, hornblende and apatite grains are present.

A concentrate from the original sample includes occasional angular garnet and hypersthene up to 0.2 millimeter; hornblende flakes up to 0.08 millimeter in length are common. Other grains include sphene, rutile and apatite. Zircon is rare and never euhedral.

Sand portion of number 8 contains rock fragments up to 4 millimeters in diameter, clear subangular quartz up to 0.2 millimeter, a few rounded and frosted quartz grains, and rusty aggregates. One well-preserved small bivalve and many foraminifera are present.

[5] Sample is not easily deflocculated, and the accuracy of mechanical analysis has been sacrificed to the preservation of the organic content. The figures given may, however, be taken as a fair estimate.

Silt grade contains an appreciable amount of carbonates. Under the microscope the grains are seen to be mainly quartz with some feldspar, occasional hornblende brown and green biotite, and plagioclase. The size of most of the silt grains is of the order of 0.02 and 0.03 millimeter; a few are between 0.05 and 0.08 millimeter in diameter.

A concentrate from the original sample contained a few euhedral zircons, one 0.2 millimeter long, and garnets up to 0.1 millimeter; hornblende is the commonest mineral, and most of the grains are 0.06 millimeter in length. Of the apatite grains present, some are roughly prismatic up to 0.05 millimeter in size but most of them are irregular and equidimentional.

Sample number 9 contains foraminifera, radiolaria and diatoms; the diatoms are mainly discoid forms.

Silt grade contains considerable carbonates. Under the microscope the material is seen to be mainly quartz, with some feldspar, plagioclase, cherty grains, occasional hornblende, and a few biotite flakes. Most of the grains are 0.03 to 0.07 millimeter in diameter.

A concentrate from the original sample shows a few grains of zircon, considerable hornblende, some apatite, irregular garnets up to 0.08 millimeter, and deeply colored rutile up to 0.05 millimeter. There are also a few grains of epidote and dirty tourmaline.

In number 10 the sand grade contains one pebble 8 millimeters long, a few well-rounded and etched quartz grains up to 1 millimeter, fine-grained red schistose rock fragments, one angular quartz pebble 4 millimeters in diameter, some sharp, fine sand, and many foraminifera. Silt portion contains carbonates. Under the microscope, grains show quartz and feldspars, with occasional plagioclase, some biotite flakes and hornblende. Size of grains is of the order of 0.01 millimeter to 0.03 millimeter with a few 0.07 to 0.01 millimeter. A concentrate from the original sample shows hornblende, a few zircons, apatite, tourmaline and rare garnet and hypersthene.

Sample number 11 shows in the undeflocculated material particles 0.01 to 0.03 millimeter in diameter, and their distribution among the aggregates suggests that the original sample contains more than 80 per cent of clay. The sample contains foraminifera. Concentrate shows hornblende flakes up to 0.08 millimeter; other grains include zircon, garnet, green tourmaline with inclusions, apatite and rarely rutile.

Seven grams of sample number 12 were examined. After removal by elutriation of the clay grade the sample showed much undeflocculated ma-

terial; under the microscope all particles are seen to be very fine, and the sample is, therefore, very high in clay. This residue is calcareous, and contains foraminifera and diatoms. A concentrate from the original sample shows hornblende flakes up to 0.05 millimeter, zircon, garnet, tourmaline and apatite.

The mechanical analysis shown below of two samples of Pleistocene marine clay from the clay pit at Billings Bridge at Ottawa, placed for comparison in proximity with the analyses of samples 4 and 8 of the earthquake zone, indicate that some of the Ottawa Valley clay of Pleistocene age is comparable in relative proportions of sand, silt and clay with some of the sea-bottom samples from the earthquake zone.

	Sand (Per cent)	Silt (Per cent)	Clay (Per cent)
Number 4	10	32	58
Ottawa A	7	29	64
Number 8	2	38	60
Ottawa B	3	39	58

Chemical Analysis

Chemical analysis of the sediments has been limited to determination of the carbonates present in three of the finer-textured samples. The results as determined by Mr. R. T. C. Fabry are shown below:

	Number 2	Number E	Number 17
CaO	8.68	3.97	5.53
$CaCO_3$	15.48	5.18	9.86
MgO	2.90	2.60	2.11
$MgCO_3$	6.07	5.43	4.30

The $CaCO_3$ and $MgCO_3$ are calculated from the amounts of CaO and Mgo stated.

The analysis of three samples indicate the minimum and maximum amounts of carbonates present to be 10.61 and 21.55 per cent and the mean 15.44 per cent. Samples of blue mud taken by the *Challenger* Expedition south of Halifax at depths of 1,250 and 2,020 fathoms yielded 16.25 and 27.75 per cent of calcium carbonate.[6] Murray and Renard's estimate of the mean percentage of $CaCO_3$ for various deep-sea deposits of blue mud with a mean depth of 1,500 to 2,000 fathoms is 9.41,[7] very near the $CaCO_3$ content of sample 17 from 1,850 fathoms with a percentage of 9.86.

[6] John Murray and A. F. Renard: Deep-sea deposits, *Challenger* Expedition, 1891, p. 52.

[7] Idem, p. 230.

Organic Content

Sediments representing six of the samples, numbers 4, 6, 11, C, D and E, from depths ranging from 1,375 to 2,000 fathoms, were submitted to Dr. Parker D. Trask for estimation of the organic content. Dr. Trask has kindly furnished the following statement:[8]

"The sediments sent me from the continental slope and abyssal deeps southwest of the Grand Banks contain very little organic matter. Their content of nitrogen ranges from 0.06 to 0.09 per cent, which indicates that they do not contain more than 1 per cent organic matter. They are only slightly richer than the samples I have from various parts of the open Atlantic. This is very interesting because their position near the edge of the Grand Banks would lead one to think that they might be enriched by organic material washed from the floor of the Banks. I do not have sufficient data from this region to hazard an explanation of the cause of this relative poorness in organic content."

Biological Elements

DIATOMS

Diatoms from two of the samples were sent to Dr. Albert Mann, diatomist, Carnegie Institute, Washington, who writes:

"I have made merely a hasty examination of the two double samples dredged south of Newfoundland. They show no local diatoms, merely a few valves that sea currents have dropped at those places. I find no trace of bottom species, but scanty specimens of single valves of such plankton species as *Coscinodiscus oculis-iridis* E., which is common all along the northern Atlantic coast and would inevitably be found in a sample of the detritus from the floor of the sea. Not a single member of the genus Navicula seems to be present, as would be the case were the diatoms of local growth. In fact at the depths given—1,530 and 1,900 fathoms—diatoms could not live."

FORAMINIFERA

Some of the samples show an abundance of foraminifera. Dr. J. A. Cushman has kindly studied these and furnished the following list of species recognized:

[8] Personal communication from Dr. Parker D. Trask, who is associated with American Petroleum Institute Research Project 4, supported by the Rockefeller grant.

	Station 4	Station 8	Station 10	Station 12
Ammochilostoma pauciloculata (H. B. Brady)	x			
Angulogerina angulosa (Williamson)			x	x
Buliminella spinigera Cushman			x	
Bulimina elegans d'Orbigny, var. *exilis* (H. B. Brady)				x
Bulimina inflata Seguenza			x	
Cassidulina crassa d'Orbigny				x
Cassidulinoides bradyi (Norman)			x	
Cassidulina laevigata d'Orbigny		x	x	x
Elphidium incertum (Williamson)	x	x	x	
Epistomina elegans (d'Orbigny)			x	x
Globigerina dubia Egger	x		x	
Globigerina bulloides d'Orbigny				x
Globorotalia menardii (d'Orbigny)				x
Globorotalia truncatulinoides d'Orbigny				x
Lagena hexagona (Williamson)		x	x	
Nonion labradoricum (Dawson)		x	x	x
Orbulina universa d'Orbigny				x
Patellina corrugata Williamson		x		
Pullenia sphaeroides (d'Orbigny)			x	
Pullenia quinqueloba (Reuss)				x
Pulvinulinella culter (Jones & Parker)	x			
Saccammina sphaerica (G. O. Sars)				x
Sigmoilina celata (Sequenza)	x			
Uvigerina peregrina Cushman	x	x	x	x
Verneuilina bradyi Cushman			x	

In the samples containing the finest silts no foraminifera were found. Two new species not included in this list will be published in the Journal of Paleontology.

MOLLUSCA

A single pelecypod shell is the only representative of of the mollusca observed in the samples. Prof. H. A. Pilsbry has kindly supplied the following observations on this shell:

"The small pelecypod from bottom sample number 8 is a *Yoldiella* very close to *Y. inflata* Verrill and Bush, but differing in being (*a*) slightly wider; (*b*) beaks a little nearer the middle; (*c*) teeth more numerous; and (*d*) hinge noticeably wider.

"In each case, the difference is small; with one specimen, I hesitate to make a decision, but as in the opened specimens before me in lots of *Y. inflata* from

4 stations, all have the tooth plate decidedly more slender. I am disposed to rank your form as very closely related but not quite identical specifically.

"*Y. inflata* varies to forms slightly longer than the type figure, that being one of the roundest."

Source of Sediments

The bottom samples represent an area that lies on the border of the great melting ground for icebergs and ice-floes. Icebergs from both the east and the west coasts of Greenland travel with the Labrador current down the east coast of Newfoundland into the region of the Grand Banks, bringing with them glacial till formed by the Greenland ice-cap. Some move westward along the southern coast of Newfoundland toward the mouth of Cabot Strait; others move south and east into the area where contact of the cold Labrador water with the warm waters of the Gulf Stream produces a complex series of eddies and currents in which bergs follow oval or erratic courses until they disintegrate in the warm waters of the Gulf Stream. On the border line between the cold and warm currents a difference of 22 degrees in temperature has been noted within a ship's length. In this zone of iceberg melting Robert de C. Ward observed one berg estimated to contain 36,000,000 tons of ice.[9] One of those he observed at close quarters had two distinct streaks of dirt in it. Elisha K. Kane had an unparalleled opportunity to study bergs at close quarters, during the months his ship was drifting through Baffin Bay ice-floes. He states:[10]

"Of nearly five thousand bergs which I have seen, there was, perhaps, not one that did not contain fragmentary rock. A walk over the berg would disclose them, either clinging partially imbedded in their slopes, or in the form of pebbles and still smaller fragments, penetrating in cylindrical cavities deep into the substance of the berg."

It is well known that the lower layers of the icebergs, which can seldom be seen, carry great quantities of land debris. During the Glacial period icebergs must have drifted far south of their present southern limit, which is little, if at all south of the area which produced the bottom samples under consideration. Good evidence of this former greater southern drift of icebergs and the consequent greater southern extension of their distribution of glacial deposits is furnished by the 490-pound boulder

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[9] Robert de C. Ward: A cruise with the international ice patrol. Geogr. Rev., vol. 14, 1924, pp. 54, 58.

[10] Elisha K. Kane: The U. S. Grinnell Expedition in search of Sir John Franklin, 1854, p. 457.

brought up from a depth of 1,340 fathoms more than 100 miles south of Halifax.[11]

Associated with the clay, mixed with sand and gravel containing ice-scratched pebbles, which the icebergs and flow ice has been showering on the sea-bottom around the Grand Banks since the beginning of the Glacial period, is much blue-and-gray mud often overlain by red clay, some of which may have been brought from the south by the Gulf Stream. Some of this fine material shows evidence of stratification; the specimen in which this is most marked, number 6, comes from a depth of 1,100 fathoms. Stratification of deep-water deposits is probably much more common than is generally supposed. Murray and Hjort report distinct traces of stratification in depths as great as 2,966 fathoms in the Bay of Biscay. Emil Philippi believed that stratification on the sea-floor is not the exception but the rule.[12]

Thus it appears most probable that in the area from which the samples came the greater part of the unconsolidated sediments, including the fine-textured clays, some of which are laminated, have been transported by floating ice from Greenland and other northern regions. A part of these sediments may represent current transported materials derived from marginal glacial drift deposits which according to Poole [13] the Nova Scotia ice-sheet deposited on the seaward edge of the continental shelf.

Behavior under Earthquake Conditions

The position of most of the cable breaks caused by the earthquake of November 18, 1929, suggested the hypothesis, accepted in most of the papers dealing with this earthquake,[14] that there were two faults approximately 375 miles in length parallel to the axis of the submarine extension of Cabot Strait, as shown on Professor Gregory's sketch map published [15] soon after the earthquake (figure 1). Movement along these two faults affords a satisfactory explanation of most of the cable breaks, but it does not explain the series of ten breaks in one cable at intervals of 5 or

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[11] John Murray and John Hjort: Deep-sea deposits. Scientific Results. *Challenger* Expedition, 1891, p. 52.

[12] John Murray and John Hjort: Depths of the ocean. 1912, pp. 174, 200.

[13] H. S. Poole: Features of the continental shelf of Nova Scotia. Proc. & Trans. Roy. Soc. Can., vol. 12, sect. iv. 1906, p. 80.

[14] E. A. Hodgson and W. W. Doxsee: Proceedings, 1930 Meeting. Eastern Sec., Seis. Soc. Amer., p. 73.

A. Keith: The Grand Banks earthquake. Suppl. to Proc. 1930 Meeting, Eastern Sec., Seis. Soc. Amer.

[15] Nature, vol. 124, 1929, p. 945.

10 miles,[16] or the north to south progression of cable breaks, with an interval of 13 hours between the first and last break; such accessory factors as the influence of different types of bottom and of currents must be called upon to complete the hypothesis.

Since the sea-bottom most affected by the 1929 earthquake lies within the zone where ice-floes have been depositing sediments from various northern sources since early in the Glacial period, these unconsolidated sediments have probably reached a considerable thickness. Whether they have the till-like character of some of the samples or the soft plastic nature of others, they would react to earthquake disturbance as "soft ground." The very different behavior of hard and soft or unconsolidated rocks under earthquake stresses is well known. In the San Francisco earthquake of 1906, Harry O. Wood found evidence that the damage was ten times as great in certain broad areas of soft ground as in other nearby areas of rigid ground.[17] In soft ground both the vertical and horizontal movements are more violent than in rigid ground.

The damage to cables crossing the area near the epicenter has been described as follows:[18]

> "Four Atlantic cables were broken at once and eight others went out of service at intervals up to 13 hours later. In each case the cables were broken at multiple points. The breaks were distributed miles apart, the extremes of the sections within which all the breaks on any cable lay being separated, in some cases, more than 150 miles. In the case of one cable there were at least ten breaks spaced at distances of 5 or 10 miles. Two cables were buried for more than 100 miles so that they could not be located."[19]

The New Madrid earthquake of 1811 and 1812 may profitably be considered in this connection because it was of comparable magnitude with the 1929 earthquake and both acted upon unconsolidated sediments. Consideration of the "sunk lands" of southwestern Missouri and northeastern Arkansas, and of the extrusion of sand and water which was associated with their development during the 1811 earthquake, suggests one of the factors involved in the burying of many miles of cables in the earthquake of November, 1929. One observer of the 1811 earthquake states that "the earth was observed to roll in waves a few feet high, with visible depressions between. By and by these swells burst throwing up large volumes of water, sand and coal. . . . When the swells burst, fissures were left running in a northern and southern direc-

[16] Mr. Higgins: Proceedings, 1930 Meeting. Eastern Sec., Seis. Soc. Amer., p. 81.
[17] John R. Freeman: Proceedings, 1930 Meeting. Eastern Sec., Seis. Soc. Amer., p. 35.
[18] E. A. Hodgson and W. W. Doxsee: Op. cit., p. 72.
[19] Mr. Higgins: Op. cit., pp. 81, 88 (discussion of paper by Hodson and Doxsee).

tion and parallel for miles. Some were 5 miles long, 4½ feet deep and 10 feet wide." A second severe shock formed fissures and lakes.[20]

Another observer of this Mississippi Valley earthquake states that "some of these fissures immediately closed up after they had vomited forth sand and water." Hundreds of acres were covered with sand which issued from the numerous fissures. Prof. J. W. Foster was told, by an eyewitness, of fissures 600 to 700 feet long and 20 to 30 feet wide, "through which water and sand spouted 40 feet high." [21] These accounts of the New Madrid earthquake from eyewitnesses are supported by the observations of geologists who have since visited the region. Shepard states [22] that "along the edges of the cracks and fault-scarps large deposits of sand are frequently found." He also reports low mounds of fine white sand 3 to 4 feet high and 20 to 100 feet in diameter which are "scattered over the whole district."

If the New Madrid earthquake could set up, in the soft alluvial deposits of the Tennessee and Arkansas lowlands, billows which when they broke into fissures would bring to the surface quantities of sand from lower levels, we might expect a notable effect from such earthquake waves in disturbing and redistributing the very mobile sediments which form much of the sea-bottom southwest of the Grand Banks. This might be expected to result in deeply covered cables.

Acting in connection with the fissured sea-bottom produced by the earthquake, bottom currents due to tidal action or the landward banking up of surface water under storm conditions, were probably a factor of considerable importance in burying the many miles of cable which the repair ships found covered after the earthquake. Since the impression has prevailed rather widely that current action, like wave action, is limited to very moderate depths on the continental shelf, if may be desirable before discussing this factor to cite some evidence for the soundness of Clement Reid's view that "tidal scour may go on at any depth, provided the current is confined to a narrow channel so as to obtain the requisite velocity." [23] In laying the Falmouth cable near Gibraltar, striking evidence of vigorous current action was found. "At 500 fathoms the wire was ground like the edge of a razor and we had to abandon it and lay a cable well inshore." [24] South of the Azores, Hjort found tidal cur-

[20] E. M. Shepard: Jour. Geol., vol. 13, 1905, p. 47.
[21] E. M. Shepard: Op. cit., p. 57.
[22] E. M. Shepard: Op. cit., p. 52.
[23] C. Reid: Submerged forests. New York, Putnam's Sons, 1913. p. 85.
[24] Quoted by T. Wellard Reade: Tidal action as an agent of geologic change. Philos. Mag., vol. 25, 1888, p. 514.

rents of considerable strength as deep as 800 meters.[25] The impossibility of anchoring in great depths makes it difficult to obtain proof of the existence of bottom currents, but Murray and Hjort reached the conclusion that their observations at one station "prove the existence of tidal currents in the Atlantic Ocean even where it is very deep.[26]

Assuming the existence of sea-bottom currents in depths as great as 2,000 fathoms or more, as I think we must in view of the above citations, let us consider the part played by these currents in redistributing unconsolidated deposits immediately after the fissuring of the sea-bottom, and in the remarkable north-to-south progression of the cable breaks pointed out by Hodgson and Doxsee in their statement that "the farther the cable lay from the adopted epicentre the later the break occurred." [27] The earthquake occurred when the tide was half-way up on a day when an exceptionally high tide was expected.[28] This means that at the time of the quake bottom tidal currents were probably running nearly at maximum strength up the Cabot Strait depression in the vicinity of the epicenter as placed by Hodgson and Keith, and that they were near flood or slack stage in the region of the more southerly cable break 100 to 350 miles south of the epicenter. The relative stability of the unconsolidated sediments before the quake was destroyed in the immediate vicinity of both the major and minor faults and fissures produced by the earthquake. We may assume that sapping and redistribution by currents of the unconsolidated sediments along resulting fault-scarp faces would begin immediately after the earthquake and proceed most actively where the bottom tidal current was near the middle of flood or ebb flow, and least actively where the tidal phase was near ebb or flood. Landslides or mudslides would result. Owing to the stage of the tide near the epicenter at the time of the earthquake, an active current with resulting cable breaks would not be expected far to the south of the epicenter for some hours after the quake. Slumping or down slipping from the scarp face toward the downthrow side of a fault in till-like clay and softer deposits would be greatly stimulated by the first tidal current after the scarps were formed. Such a submarine landslide, taking place where the cable was already buried on both sides of the scarp by the submarine disturbance at the moment of the quake, might involve hundreds of acres, and a cable stretched across the direction of movement would doubtless be snapped

[25] John Hjort: The Michael Sars North Atlantic Deep-Sea Expedition, 1910. Geogr. Jour., vol. 37, pp. 349-377.
[26] John Murray and John Hjort: Depths of the ocean, 1912, p. 247.
[27] Op. cit., p. 79.
[28] Op. cit., p. 79.

like a cord. Under such conditions a cable would be broken by stresses comparable with those which will sometimes split a spruce tree from the roots upward when a large section of frozen river bank caves into a sapping current.

The progressive north-to-south order of the breaks appears to square well with the hypothesis that most of the breaks to the south of the epicenter were caused by submarine landslides developed through the agency of bottom currents which in turn were produced chiefly by the gale blowing at the time of the earthquake. On the afternoon of the earthquake a bottom seaward current of more than usual strength probably resulted from the banking up action of the storm which was expected to produce a very high tide that afternoon.[29] John Milne states that the Balboa Spanish cable laid in 1872 broke periodically, usually in the month of March during or after a northwest gale. The break occurred about 30 miles north of Balboa, and when repairs were made 4 or 5 miles of cable were invariably found covered. These breaks were attributed to submarine landslides caused by a heavy submarine current due to the piling up of surface water.[30]

Poole's chart [31] of the Atlantic off Nova Scotia shows an extensive depression or basin on the continental shelf between the mainland and Sable Island which connects with the Atlantic abyss through a deep cleft known as the Gully, in the eastern margin of the continental shelf. Soundings at the mouth of The Gully by the cable ship *Minia* "gave a depth of 847 fathoms with so rapid a drop within a cable's length that as the ship drifted the grapnel could not be kept on the bottom." [32] On either side of the mouth of The Gully depths of 50 fathoms and less prevail. This deep notch in the southern border of the shelf connected with the large lake-like basin north of Sable Island is one of the places where sea-bottom topography affords the conditions essential for both tidal currents of exceptional strength and bottom currents resulting from special atmospheric conditions. Sambro channel south of Halifax is another breach in the eastern front of the shelf which connects with a second extensive basin on the continental shelf. Probably other as yet undiscovered notches in the sea front of the continental shelf afford conditions favoring the development of strong bottom currents during stormy periods.

[29] E. A. Hodgson and W. W. Doxsee: Op. cit., p. 79.

[30] John Milne: Suboceanic changes. Geogr. Jour., vol. 10, 1897, p. 272.

[31] H. S. Poole: Features of the continental shelf off Nova Scotia. Roy. Soc. Can., vol. 12, sec. iv, 1906.

[32] H. S. Poole: Op. cit., p. 75.

The marine clay of the Ottawa Valley, when thoroughly saturated with water in the spring, sometimes moves in large masses in the direction of a river scarp in the same manner that the marine clay of the fault-zone probably moved when the cables were broken. In the Saint Alban landslip of April, 1894, an area of more than 3 miles in length with a maximum width of 7,700 feet moved bodily into the Sainte Anne River in Quebec. Five or six farmhouses were destroyed and four lives were lost in this slide.[33] In another type of slide, which was carefully studied by the Geological Survey of Canada, 86 acres of Leda clay and saxicava sands moved out in 3 hours through a break in a river scarp about 200 feet wide and distributed itself along the River Blanche in Quebec over a distance of about 2 miles. In this River Blanche slide the surface blocks of relatively solid earth floated out in a subsurface mass of fluid clay. These and many smaller landslips in the marine clays of the Ottawa Valley give significant evidence of the ease with which these silty clays and sands will move toward a scarp face when saturation by spring rains and floods changes them into something like their original mobile submarine condition. The silt content of some of the earthquake zone samples is comparable with that of samples of marine clay at Ottawa (see page 565) and should slip or flow along scarps with equal facility.

Sediments of the Cabot Strait depression would be expected to react far more promptly along fault-scarps to the sapping of a tidal current than the inland marine clays, long under subaerial conditions, would to simple saturation with water. The destruction of buildings and fences which landslides sometimes bring about when these inland clays are restored to nearly their original submarine condition of saturation enables us to visualize in some degree the way in which the fault-scarps, under the stimulus of bottom current sapping probably brought about extensive slipping of large masses of the clay and consequent breaking of cables buried in it.

[33] G. M. Dawson: Remarkable landslip in Portneuf County, Quebec. Bull. Geol. Soc. Amer., vol. 10, 1899, p. 489.

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GEOLOGY OF THE MINGAN ISLANDS[1]

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INTRODUCTION

On two previous occasions the writer has presented or assisted in presenting certain aspects of the geology of the Mingan Islands.[2] He has made three visits to these islands. The first was in 1909, when some of them were studied by means of a fishing boat owned and sailed by Selas Poirer of Anticosti Island. On that trip the islets of the Parroquet group and Mingan, Harbour, Moutange (Big Romaine), Large, Quarry, and Niapisco islands were studied. During that same summer on the return from Anticosti the writer was compelled to remain for several days in Havre Saint Pierre (Eskimo Point), and the opportunity was taken to study Eskimo Island and the section on the west side of Clearwater Point. The second visit was in the summer of 1925, when Inner and Outer Birch, Harbour, Moutange (Big Romaine), and Moniac (Little Romaine) islands, Point des Morts, and the west side of Clearwater Point were studied in detail, and Sainte Genivieve, Hunting (Betchewan), and Saint Charles islands were carefully examined over parts of their sea-cliffs. The

[1] Manuscript received by the Secretary of the Society January 12, 1931.

[2] Charles Schuchert and W. H. Twenhofel: The Mingan-Anticosti Island section. Bull. Geol. Soc. Amer., vol. 21, 1910, pp. 696-693. W. H. Twenhofel: Geology of the Mingan Islands. Bull. Geol. Soc. Amer., vol. 37, 1926, pp. 535-550.

last visit was in the summer of 1929, when Hunting, Large, Eskimo, and Harbour islands and the entire coast from Appititatte Bay west to beyond the village of Magpie were carefully studied. In addition the pre-Cambrian crystallines were studied at Pillage Bay, Magpie, and in the Saint John Mountains above the Mingan and Saint John rivers.

For the opportunity of making the 1925 and 1929 expeditions the writer is indebted to the Research Committee of the University of Wisconsin, of which Dean C. S. Slichter is chairman. The 1909 visit was financed by Peabody Museum of Yale University.

There occur on Anticosti and the Mingan Islands plants which are representative of those now living over western North America and which probably lived over eastern North America in pre-Glacial times. These plants have been known for many years, but their detailed study and the pointing out of their significance are due to Prof. M. L. Fernald, of Harvard University, and Professor Marie-Victorin, of the University of Montreal.[3] The occurrence of these plants on the Mingan Islands and Anticosti suggest the possibility that certain areas on Anticosti, and possibly on the Mingan Islands, may have escaped the later glaciation, as did some areas on Newfoundland and Gaspé. Fernald seems to be of the opinion that the occurrences on the Mingans and Anticosti are the results of post-Glacial migration rather than of their survival on these islands in spots which escaped glaciation, whereas Marie-Victorin suggests (1929, pages 49 and 58) that some points of Anticosti and Mingan may not have been covered by the ice-sheets, he supposing that the ice-front consisted of a series of more or less long tongues and that Mingan Islands and Anticosti lay between two glacial lobes.

The 1929 expedition of the writer to the Gulf of Saint Lawrence was primarily for the purpose of seeing if any evidence of unglaciated areas existed on Anticosti and the Mingan Islands and on the Saint John Mountains in the immediate backland, and secondarily to increase the collection of fossils from the Mingan Islands strata. Unfortunately Anticosti Island could not be visited at that time.

It would seem that the writer's previous visits to Anticosti and the Mingan Islands should have demonstrated the extent of glaciation, but these previous visits were for other purposes than study of the glacial geology, and moreover, at the times of the previous visits, the hypothesis

[3] M. L. Fernald: Persistence of plants in unglaciated areas of Boreal America. Mem. Amer. Acad. Arts and Sci., vol. xv, 1925. Frère Marie-Victorin: Le Dynamisme dans la Flore du Quebec. Cont. Labr. Bot. Univ. Montréal, no. 13, 1929. Deux Epibiotes remarquable de la Minganie. Ibid., no. 12. 1928.

was held that the islands had been glaciated and thus search may not have been so careful as it might otherwise have been.

Geologic Section of the Mingan Islands and the Mainland

The rocks of the Mingan Islands consist almost entirely of limestones and dolomites. In some places on the adjacent mainland, as opposite Moutange Island, the rocks consist of crystallines, but in most places they are like those of the Islands, or are post-Glacial stratified marine sands and clays. Limestones or dolomites form the coast from Appititatte Bay on the east, westward to the bay on the west side of Clearwater Point, except for an area on the east side of Pillage Bay, where various crystallines make up the rocks of the shore, and a short space in the head of Trilobite Bay. From the bay on the west side of Clearwater Point, post-Glacial marine sands and clays form the coast to about 1½ miles west of Havre Saint Pierre, where limestones appear and continue to the head of the bay on the west side of Point des Morts, whence the coast toward the west, with some interruptions, is formed of crystallines to a short distance west of the mouth of Romaine River. There they give place to stratified sands and clays, and these form the coast westward to a short distance east of the mouth of Magpie River, where they give place to crystallines. On the west side of Pillage Bay, limestones form a high ridge which extends inland for several miles, and Sainte Genivieve Mountain, inland on the east side of the bay, is largely, if not wholly, formed of limestones. It seems probable that limestones form the rock inland for several miles from Appititatte Bay to the west side of Point des Morts. The geologic section is as follows:

Cenozoic. Post-Glacial marine sands, clays, and gravels, containing marine fossils in some beds. Maximum thickness probably exceeds 125 feet.

Paleozoic.

Ordovician.

Chazy-Black River. Mingan limestones. Mostly thick-bedded limestones which are usually crystalline. Contain few fossils. Bedding planes are quite even, and some of the beds are as much as 5 or more feet thick. At the base is a variable thickness of sandstones and shales, the thickness ranging with locality from less than 10 to more than 30 feet. The sandstones and shales are both wave- and current-marked, and the latter are mud-cracked and have

what appear to be rain impressions on some layers. The total exposed thickness of the formation seems not to exceed 140 feet.

Beekmantown. Romaine dolomites. More or less massive gray crystalline dolomites with beds ranging in thickness up to 10 feet. Many beds have wavy bedding owing to their being partly of algal origin. Fossils are extremely rare. These dolomites seem to rest directly on the pre-Cambrian crystallines with a few feet of sandstones intervening. The thickness is slightly over 200 feet.

Pre-Cambrian. The pre-Cambrian rocks consist of various granites, labradorite, various gneisses and schists, quartzite, and other igneous and metamorphic rocks. The bedding and foliation planes are at high angles where they have been seen by the writer. Little work has been done on these rocks, and their varieties, distribution, and structure are essentially unknown.

Geologic Structure

The 1929 study of the Mingan Islands gave some additional information relating to their structure and the possible structure of the rocks beneath the channel between the Mingan Islands and Anticosti. In general, the strata dip to the south, but reversals are common, and for extensive areas the dips are negligible. Thus, on Large Island, the largest of the group, with a north-south diameter of about 4 miles, the top of the Romaine formation is not over 40 feet above sealevel at the north end of the island, and reaches sealevel at the north point of the deep bay on the east side, more than a mile away, thus showing a dip to the south of less than 40 feet in one mile; the top continues at about sealevel for nearly a mile farther south. In the entire length of the island it seems probable that not more than 150 feet of strata are exposed along its east shore, thus giving a dip to the south of less than 40 feet to a mile. This inclination, the reversals, and the horizontal beds have a bearing on the thickness of rocks concealed between the Mingan Islands and Anticosti. Logan gave the inclination of the Mingan-Anticosti sequence as 90 feet per mile, thus postulating a concealed thickness in the North Channel of about 1,700 feet.[4] The writer's observation of an inclination of 40 feet per mile would indicate a thickness of only about 800 feet, and possibly even that figure may be too large. The latter figure harmonizes

[4] W. E. Logan: Geology of Canada, 1863, pp. 220-221.

with the depth of the channel between the Mingan Islands and Anticosti.

It need hardly be said that a marked unconformity exists between the pre-Cambrian and Ordovician and another between the Ordovician and the Pleistocene. There is also an unconformity between the Romaine and Mingan formations. In small exposures the impression is given that the lowest bed of the Mingan formation always rests on the same bed of the Romaine formation, but where long exposures parallel to the dip occur, as on the east side of Large Island, it is very obvious that the

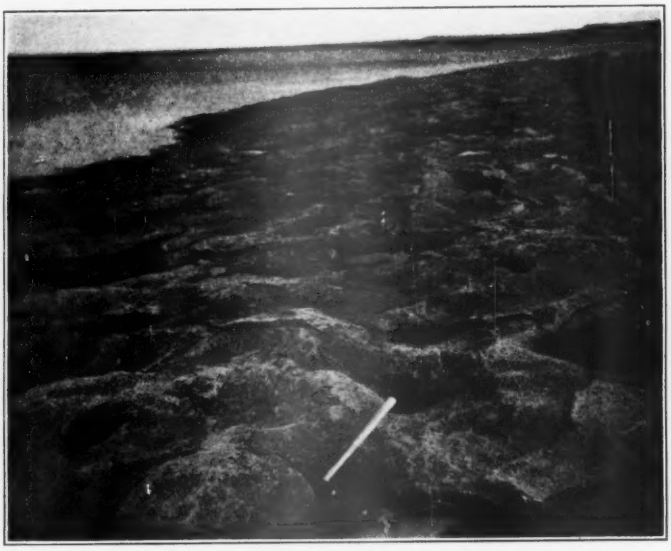

FIGURE 1.—*Algal Reef of the Romaine Formation*

This location is on the east side of Large Island.

basal sandstones of the Mingan rest on different beds of the Romaine. South of the south point of the deep bay on the east side of Large Island there may be seen an exposure of this contact in which the basal bed of the Mingan rests on eight different beds of the Romaine, the lowest bed being toward the south and the contact rising from bed to bed to the north.

FOSSILS OF THE MINGAN ISLANDS FORMATION

Generally speaking, the Mingan Islands formations contain few fossils; the Romaine formation contains hardly any. In some beds of the

Romaine are found a few poor casts of flat-spired gastropods and straight and coiled cephalopods. Some beds are composed almost entirely of cryptozoon algæ (figure 1). On the east side of Large Island, about 10 feet below the top of the Romaine formation, there was found a zone of fine-grained dolomite in which impressions of fragments of one species of trilobite and casts of one species of brachiopod are not uncommon. The Mingan formation is more fossiliferous. The sandstones and sandy limestones at the base contain an abundance of *Rhynchotrema orientalis* and an occasional specimen of a few other species of brachiopods. A zone about 30 to 50 feet above the base contains fossil sponges of two species, one a large vase-shaped form about 8 inches in diameter at the top. This zone may be seen on Niapisco Island, on the west side of Clearwater Point and at Ammonite Point, this last name being a misnomer, as no ammonites and few cephalopods are present there. The name was probably given through an erroneous identification of the occasional large *Maclurea* found there. The upper beds of the Mingan formation are characterized by occasional large *Maclurea,* a few straight and coiled cephalopods, one of the former known to attain a length of more than 18 inches, and occasional trilobites, one *Isotelus*-like form known from its fragments to have reached a width of 6 inches across the cephalon.

A limestone bed about 50 feet above the base of the Mingan on the west side of Large Island contains mud cracks, showing that the bottom was exposed during its formation. On the west side of Clearwater Point cross-laminated limestones occur about the same distance above the base of the Mingan formation.

The scarcity of fossils is probably due to the work of scavenger organisms, which ground the material so fine that much of it was recrystallized to form the present limestones. In the Romaine formation this crystallization was so nearly complete as to almost totally eliminate organic matter.

Pre-Glacial Physiography

The accompanying map (figure 2), drawn from data taken from the hydrographic charts of the Saint Lawrence region, is an attempt to represent the drainage as it existed in pre-Glacial times. No doubt the map contains considerable error in detail, as there must have been deep erosion on the elevations during the existence of the ice-sheets and some contemporaneous and subsequent filling of the lowlands; but it is thought that the major features are correct.

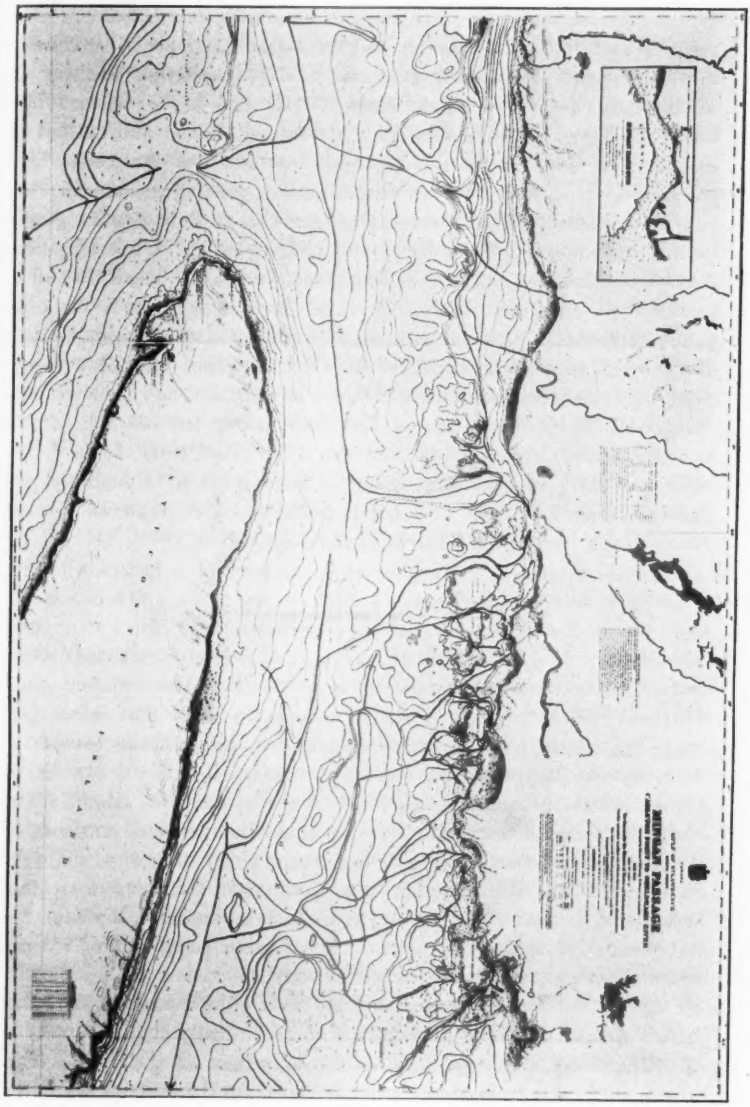

FIGURE 2.—*Pre-Glacial Drainage of North Side of the Gulf of Saint Lawrence*

It is considered probable that the uplifted middle to late Mesozoic peneplain of eastern North America had the Saint Lawrence River flowing into the Atlantic somewhere southeast of Newfoundland, reaching the sea through what is now Cabot Strait. A tributary to that ancient Saint Lawrence flowed north of what is now Anticosti Island and around the east end to enter the Saint Lawrence southeast of Anticosti. This stream was separated from another tributary passing around the west end of Anticosti by a divide extending from Cap de Rabast to the general locality of Inner and Outer Birch and Large islands. These tributaries may be designated as East and West rivers from their localities and directions. The former received most of the drainage from the north slopes of Anticosti and had as tributaries the streams of Labrador from Mingan eastward. The Romaine River of that time may have entered East River between Niapisco and Quin islands, as shown on the map. Mingan River may have entered East River along the east side of what is now Harbour Island and between the Birch Islands and Large Island, or it may have entered West River by flowing south through the deep passage between Mingan and Birch islands. Saint John and Magpie rivers were a part of the West River drainage.

Anticosti Island is the unsubmerged summit of a cuesta whose dip slope bordered the Saint Lawrence River on the north, and whose escarpment was to the north. It is continuous westward in the Parent Bank. The Mingan Islands at that time formed a second cuesta with double ridge. Its westward continuation is in the Cod and adjacent banks. This was crossed by many streams from the north, so that submergence led to the development of numerous islands. The lowland between the Anticosti and Mingan ridges was cut in the strata occurring between the highest strata of the Mingans and the lowest of Anticosti Island. These strata are assumed to have been less resistent than those of Anticosti and the Mingans and thus to have yielded more readily to erosion. The lowland between the Mingans and the crystallines of the Laurentian Shield is assumed to have been cut on the contact between the Romaine dolomites and the crystallines, some of the erosion being in the 8 feet of white sandstones which Logan stated were exposed on the east side of Pillage Bay.[5] These sandstones do not seem to be exposed at the present time. Some sandstones are exposed on the hillside above the east side of Pillage Bay and these may be the equivalent of those described by Logan. The narrowness and the irregularities of the lowland north of the

[5] W. E. Logan: Geology of Canada, 1863, p. 287.

Mingan Islands are thought to be due to the thinness of the weak strata considered to lie below or at the base of the Romaine dolomites. The Mingan ridge was double. This arose from the occurrence of the weak beds at the base of the Mingan formation, these having determined the deep bay on the east side of Large Island, the strait between Inner and Outer Birch islands, the deep bay on the west side of Eskimo Island, the bays on the north end of Niapisco Island, the bay on the west side of Saint Charles Island, and the division of the islands into an inner and outer fringe.

The detailed character of the surface during pre-Glacial times of what now forms the Mingan Islands is not known. It is considered absolutely certain that none of the existing "flower pots," [6] now so characteristic of the surface cut on the upper beds of the Mingan formation, could have then been present. With the postulated rivers of that time, these "flower pots" would probably not have been formed with anything like their present distribution, and even if they had, the deep cutting during the Ice Age would most certainly have removed them. Even if some parts of the Mingan Islands had escaped glaciation, "flower pots" could not have survived on such parts from that time to the present, as the action of frost is very powerful in these regions, quickly shattering the rocks exposed to it.

Situation during the Glacial Period

It is certain that during the Ice Age the Mingan Islands and the land to the north were deeply buried beneath the ice-sheets. The crystallines a few miles inland, at elevations estimated at 800 to 1,000 feet, are scoured to the solid rock, which presents rounded, grooved, and roches moutonneed surfaces. Loose rock and erratics are almost entirely lacking (figure 3). The writer's examination of these mountains was limited to the region back of the Mingan Islands and west nearly to Thunder River, but in that area it is certain that the glaciation was deep and very intense. The ice must have been very thick on these uplands. Similarly, on the islands and on the limestones and crystallines of the adjacent coast the scour of the ice-sheets was deep, as is shown in Pillage Bay, on Hunting Island, the coast from Pillage Bay to Trilobite Bay (where there are no trilobites), on Clearwater and Ammonite Points, in the bay on the west side of Clearwater Point, on Point des Morts, Eskimo Island, Moutange Island, the crystallines about the mouth of Romaine River, Large Island (in the deep bay on the east side), Harbour Island (south

[6] Stacks 4 to 12 feet high at and above the present sealevel.

side), and at all places where the glacial markings are protected from marine erosion. Weak rocks and the rocks of exposed headlands show few markings of glacial erosion, but strong rocks and rocks in protected positions exhibit them in remarable development. In Pillage Bay the granites and other crystallines are fresh at the surface and are deeply furrowed. In Betchewan Bay some of the furrows in the limestones are as much as 20 feet wide and 3 feet deep (figure 4). From Betchewan

FIGURE 3.—*The crystalline uplands about 2 miles above Mingan Falls*

The elevation is estimated at from 800 to 1,000 feet and the view is looking northwest. The rounded hills in the distance seem to be glaciated.

Bay to Trilobite Bay the limestones are similarly furrowed, and in many places inland from the strand of average tide, basins have been cut out which now contain water to a depth of 6 feet. Many may be seen in the rocks of the upper parts of the beach. Similar furrowing may be seen in the bay on the west side of Clearwater Point, on Moutange Island, on Harbour Island, in the deep bay on the east side of Large Island and at several places on Hunting Island. Erratics are not abundant on any of the islands, and it is considered certain that all of the islands were so deeply buried beneath ice-sheets that all loose rocks were removed and they were without life during the presence of these sheets.

The evidence for the extent of the ice-sheets on Anticosti Island has been presented elsewhere and most of it need not be restated here. The interior of the island has not been carefully studied, but drift deposits derived from the limestones to the north have been found on the Vaurial River at an elevation of 322 feet above the present sealevel thus showing that the ice rose to that level, and as no prominent moraine exists at that level or was observed at any other level of the island, as it would if the ice had stopped there, it seems certain that the sheets must have crossed

FIGURE 4.—*Glacial Furrow, Betchewan Bay*

The furrow is about 20 feet wide and 3 feet deep.

Anticosti. As it seems probable that little of the island rises above an elevation of 500 feet and with ice-sheets a few miles to the north rising higher than any known elevation on Anticosti and cutting to solid rock to remove everything, Anticosti could hardly have escaped being overrun. Until evidence to the contrary is produced, the writer feels justified in assuming that Anticosti lay beneath one or more of the Pleistocene ice-sheets.

The writer ventures no opinion as to whether the glaciers which covered the Mingan Islands, the crystallines to the north, and Anticosti were Wisconsin or older.

Pleistocene Submergence

The islands are terraced up to 80 to 90 feet above the present sealevel, the lower terraces being marked by great trains of beach gravel. On the mainland between Clearwater Point and Havre Saint Pierre there are deposits of marine clays, sands, and gravels rising to elevations of 110 to 115 feet above the present sealevel. Similar deposits containing marine fossils may be seen from Saint John River west nearly to the mouth of Magpie River, rising to an elevation of about 70 feet at the mouth of Saint John River. Many of the islands—Large, Inner and Outer Birch, Quarry, Niapisco, Fright, Quin, Eskimo, Sea Cow, Saint Charles, Sainte Genivieve, and possibly Hunting—rise above these elevations but only for a small area making it certain that many of the islands were wholly submerged and the rest of them in large part. The high limestone ridges on the west side of Pillage Bay and Sainte Genivieve Mountain on the east side of that bay rise high above the places of positive evidence of submergence (332 feet at the top of Sainte Genivieve Mountain),[7] and these high points may have been uncovered during the times of maximum Pleistocene submergence, as may also have been the summits of some of the islands. The mountains in the backland certainly were not submerged. Thus there were many places where plants could have lived in the vicinity of Mingan Islands provided the soils there were suitable for their growth. Anticosti probably was largely submerged at the same time, but some of the higher lands may have been exposed.

Post-Pleistocene History

Since the Champlain submergence the Mingan Islands and Anticosti have risen from the water, as proved by the elevated marine clays and sands of the mainland and on Anticosti and by the terraces and "flower pots"[8] on the islands. Possibly the land may have risen higher than the present level, so that the Gulf of Saint Lawrence again became a river, this being suggested by the regularity of the submerged river channels. It is also possible that the present Gulf of Saint Lawrence was land in an interval between the ice-sheets and the Champlain submergence. It is

[7] Figures are taken from chart 431 of the Department of Marine and Fisheries of Canada.

[8] "Flower pots" are stacks and similar erosion features on the present beach and on some of the raised beaches, the finest being developed in the higher beds of the Mingan formation. When the writer's paper on the Geology of the Mingan Islands was read before the Geological Society of America in 1925, certain geologists suggested that the "flower pots" were pre-Glacial. The deep and severe glacial erosion does not well accord with that suggestion.

thought that all plant life on the islands and the adjacent mainland was destroyed by the ice-sheets and returned after their disappearance. Whether this return preceded as a whole or in part the Pleistocene submergence can not be stated. If some of the plants returned before the submergence they could have lived on the mainland and perhaps on the summits of some of the islands, thence to spread centrifugally to the margins as these were extended by the retreat of the sea. Their habitat during the presence of the ice-sheets may have been Newfoundland and Gaspé. If the Gulf of Saint Lawrence was land following the retreat of the ice, their migration to Anticosti and the Mingans would have been comparatively easy. Possibly the Gulf was land after the Champlain submergence. As little is known of the post-Glacial movement, these hypotheses are permissible, and it may be possible that the retreating ice-sheets were followed by plants advancing from Newfoundland and Gaspé.

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ARE THE GRAPTOLITES BRYOZOANS?

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(Read before the Paleontological Society December 28, 1930)

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INTRODUCTION

The authors, while enjoying the ease of a steamer chair on a joint trip to Europe in 1922, and discussing somewhat idly at first the taxonomic position of the graptolites, discovered to their mutual great satisfaction that they had arrived independently at the conviction that the graptolites are an early and long extinct branch of the bryozoans. It was then decided to bring the evidence together and jointly publish the result. Other interests have delayed the execution of this plan to the present day, but the long interval of time has also served to produce new and more conclusive evidence.

We will refrain here from giving a lengthy account of the various views that have been held concerning the taxonomic relations of the graptolites since both Elles and Wood (1901-1918) and the junior author (1904) have fully covered the ground. It may suffice to state that a large group of authors, most notably the earlier ones—Portlock, Hall, Carruthers,

[1] Manuscript received by the Secretary of the Society February 24, 1931.

Nicholson, and Allman, and later Lapworth, Frech, and Ruedemann—and all the textbooks have connected the graptolites with the Hydroid Coelenterates, or Hydrozoans, while others—as notably Neumayr, Wiman and Elles [2]—have held that the graptolites represent a wholly extinct class of unknown relationship. Wiman has strongly urged that the graptolites can not be brought under any of the now existing classes of animals. To the placing of the graptolites with the Hydrozoans, this author objects on the ground, first, that there is no Hydrozoan known which has the structure of a graptolite, and, second, that the individuals of the first order of the graptolites (the thecæ) are bilaterally symmetric, while those of the Hydrozoans possess a higher symmetry. The possible objection that hydroid thecæ also sometimes possess a bilateral symmetry is met by the statement that this can be explained by the position of the individuals on the hydrocaulus, while in the graptolites the sicula already possessed a clearly bilateral symmetry. Moreover, the graptolites do not possess a "common canal" corresponding to the hydrocaulus but each theca buds directly from the preceding.

The junior author saw evidence of the hydrozoan nature of the graptolites in his discovery of a pneumatocyst or float as part of the synrhabdosome of certain Graptoloidea (*Diplograptus, Lasiograptus*) and the presence of gonangia surrounding the base of the colonial stock, features that recalled the siphonophores. Still stronger evidence was seen by him in the presence of delicate conical appendages of the branches of specimens of *Mastigograptus tenuiramosus* (Walcott) that the senior author had collected in the Eden shale of Cincinnati. These appendages are flanked by a pair of smaller similar appendages and suggest strongly the gonothecæ and hydrothecæ of Hydroid Coelenterates, as was pointed out by the junior author (1908, page 215).

More recently Chapman (1918) described two species, *Archaeolafoea longicornis* and *Archaeocryptolaria skeatsi* from the Ordovician of Australia which from the form of the hydrothecæ [3] and the discovery of gonothecæ attached to the hydrosome in at least the first of the two, he unhesitatingly refers to the Hydroid Coelenterates of the order Calyptoblastea and the family Lafoeidæ. He places also *Mastigograptus* Ruedemann into the same order and family and points out that *Chaunograptus* Hall

[2] Miss Elles has only lately (1922, p. 168) pointed out that the resemblance to Hydrozoans "in detail breaks down." On the other hand Stechow (1920, p. 405) has described a rare, very aberrant supposed Hydrozoan-form (*Dinotheca doflei* Stechow) as suggestive of a Rastrites.

[3] Stem composed of hydrocaulus to which short thecæ are attached, that project irregularly at various angles.

also approaches his specimens so closely that it too should be referred to that group of Hydroid Coelenterates. Chapman's authoritative view thus places at least two genera of the graptolites into the Hydrozoans. As the junior author has in press the description of another species of *Chaunograptus* from the Middle Cambrian Burgess shale of British Columbia the great age of the Hydroid Coelenterates may be considered as established and as overcoming the former objection of some authors that the Hydroid Coelenterates are known only from much younger (late Mesozoic to Recent) formations and therefore not qualified to be used for comparison with the graptolites.

It would, however, be a distinctly false conclusion to infer from these discoveries that they prove the Hydrozoan nature of the graptolites in general, since *Mastigograptus* and *Chaunograptus* stand distinctly aside from the rest of the graptolites both in their habitus and mode of life, *Mastigograptus* being composed of hydrocaulus and thecæ and *Chaunograptus* being repent on shells. It is, therefore, quite possible that these must be removed from the graptolites and that they have no definite bearing on the taxonomic position of the other graptolites, but rather indicate that the graptolites as commonly conceived are not a homogeneous class but that they include a considerable number of unnaturally associated fossil types.

Bryozoan Characters of Graptolites

General Statement

The suggestion that the graptolites may be connected with the Bryozoans is not altogether new, for already in 1905, Schepotieff (see Ruedemann, 1908, page 97) on discovering the presence of a solid rod in the nemacaulus of *Monograptus* that reminded him of the similar rod in the bryozoan genus *Rhabdopleura* was led to suggest that *Rhabdopleura* may be a closer relative to the graptolites than the Hydroid Coelenterates. In this connection, however, it is important to note that, on one hand, the solid rod of the nemacaulus is a late development in the graptolites found only in the Axonophora, and that on the other hand, *Rhabdopleura* is a very aberrant form that at present is not safely placed. With another aberrant genus (*Cephalodiscus*) it now forms an isolated class (Pterobranchia) that, though in its habitus similar to the Bryozoans, has close relations with the Enteropneusta (*Balanoglossus*) and is placed on account of the supposed notochord and other characters at the base of the phylum Chordata. *Rhabdopleura,* therefore, seems no Bryozoan at all, and the notochord a different organ from the rod of the graptolites.

Let us now consider the evidence in favor of the bryozoan nature of the graptolites.

1. SICULA

Beginning with the sicula, we find that it is composed of two distinct parts as discovered by Wiman (1893) and since elaborately described by Kraft (1926). The first part (prosicula of Kraft) is a thin conical transparent body, tapering at one end into the nemacaulus and provided with a spiral band and some longitudinal strengthening rods or carinæ. This embryo-shell is abruptly followed by the tubular metasicula that shows the growth-lines of a normal theca, bears the dorsal median rod, ending into the sicular spine and from it the first theca buds near the aperture. A like structure is not found among the Cnidarians, either among the Hydrozoans or the Anthozoans, where the initial corallite, as shown by Girty (1895) in *Favosites* and by Beecher in *Pleurodictyum* (1891) and *Romingeria* (1903) and by others, is a simple conical or tubular body, the same as the later corallites, so that development is direct, a fact well supported by the recent Cnidarians. In the Bryozoans, however, in recent forms as well as in Paleozoic fossils, as brought out especially by Cumings (1904, 1905, 1912), the primary zooecium consists of a structureless tube or cup with circular base, the protoecium, which is directly continuous, though sometimes with an intervening constriction, with the ancestrula, a tube that contains diaphragms and cystiphragms as the later zooecia do and is the first zooecium. From this also bud the later zooecia. The structure is hence exactly as in the graptolites. Cumings (1912) used this structure to prove Ulrich's claim that the Monticuloporoids or Trepostomata are Bryozoans and not corals.

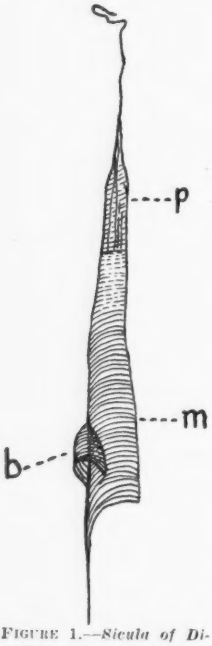

FIGURE 1.—*Sicula of Diplograptus gracilis F. Roemer (after Kraft)*
p, protosicula; *m*, metasicula; *b*, bud. × 31.

2. MODE OF BUDDING FROM SICULA

Likewise the budding from the ancestrula takes place in a mode comparable to that in the bryozoans and not as in the corals. In the latter,

as for instance Beecher (1903) has well shown in Pleurodictyum, Michelinia and Romingeria and as is found in the recent red coral and others, the primary buds come off symmetrically all around the primary individ-

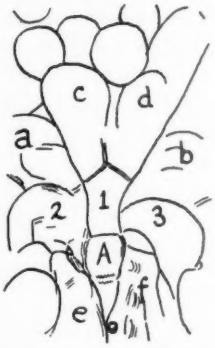

FIGURE 2. — *Transverse serial Section of a Colony of Prasopora conoidea Ulrich (after Cumings)* o, proteoecium; *A*, ancestrula; *1*, medium primary bud; *2*, left; *3*, right lateral primary bud. × 43.

FIGURE 3. — *Side-View of a normal Corallite of Romingeria umbellifera with a Circle of twelve Buds at the Summit (after Beecher).* × 4.

ual of the colony, whereas in the bryozoans it is restricted to the neck region of the ancestrula and consists of a median and two lateral buds. This condition compares well with that found in graptolites, where a primary bud forms in the neck region of the metasicula that produces two secondary buds in quick succession. A tachygenetic acceleration of this latter mode of budding would produce that of the Bryozoans, a supposition that is well supported by the fact that the graptolites appear earlier than the calcareous bryozoans and hence present the more primitive condition of the phylum.

3. *BILATERALLY SYMMETRIC THECÆ*

The thecæ of the graptolites have a fundamental bilaterally symmetric form, as pointed out by Wiman, indicating that they were inhabited by animals possessing a bilateral symmetry, such as the zooids of the Bryozoans have. The Hydrozoans, like all Cnidarians, are fundamentally radially symmetric and when the thecæ show a bilateral symmetry it is a secondary phenomenon and due to their position on the hydrocaulus.

4. LIKE HABITUS OF THE TWO GROUPS

The primitive bryozoans, namely, the Cyclostomata and Cryptostomata, are so alike in their mode of branching and general habitus in many forms to that of the graptolites that for instance a complete *Corynotrypa* colony is exactly like that of a *Clonograptus,* or *Goniograptus;* or a *Chasmatopora* like a *Desmograptus.* The separation is made by the substance of the periderm, which is calcareous in the fossil Cyclostomata and chitinous in the graptolites. As the development in all invertebrates has been from chitinous to calcareous tests, it is to be inferred that the Cyclostomata also began with chitinous constituents of the zoarium. The Ctenostomata among the bryozoans possess only chitinous zooecia today, but as Ulrich and Bassler (1904, page 262) who have referred a considerable number of fossils to the Ctenostomata have pointed out, may even in Paleozoic time have already had slightly calcareous zooecia, namely, those that are preserved, while the others, either horny or membranaceous, may have failed of preservation. And

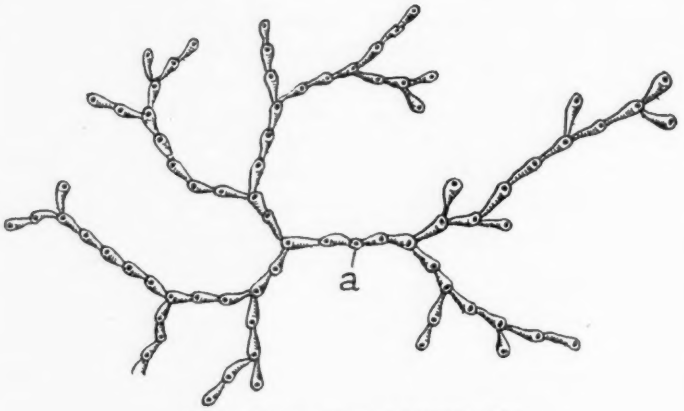

FIGURE 4.—*Corynotrypa delicatula James*
Young zoarium on Pterinea (*original*) × 9.

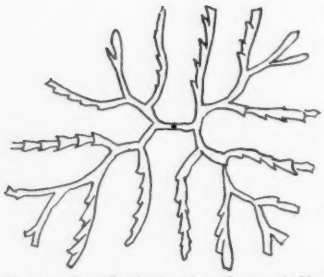

FIGURE 5.—*Goniograptus thureaui McCoy var. postremus Rued*
Young rhabdosome, × 2½. From Ruedemann.

in the case of forms as the graptolite *Ascograptus* Ruedemann and the ctenostome *Ascodictyon* Nicholson and Etheridge, which are surprisingly similar, the assignment to the graptolites, aside from the form of the thecæ, is largely made on this difference in the chemical composition of the periderm.

Comparison of details of cell-structure of such typical graptolites as the Diplograptidæ with contemporary Bryozoa, particularly many of the Cryptostomata, reveals so many similarities that it seems unreasonable to deny their fundamental genetic relationship. Of perhaps greatest importance among these simulating and probably homologous structures that are common to Diplograptidæ and Cryptostomata are (1) the division of the cells or tubes into two parts, the lower and larger, usually quadrangular part and the upper "vestibular" part, and (2) the development of "hemisepta"—both "inferior" and "superior" at the passage between the two parts of the zooecium. Indeed, excepting that the wall of the one is calcareous and relatively clear in the one and chitinous and black in the other, we find no essential difference between the appearance of the vertical section of a zooecium of such typical Cryptostomata as *Ptilodictya* or *Eurydictya* and a similar section of the cell of a *Climacograptus*. Moreover, in comparing the greatly varying zoarial features pertaining to genera of Cryptostomata we are at a loss to mention a single style that was not also adopted by one or another of the typical graptolites.

It is thus quite apparent that a number of graptolites lead over by insensible stages to the bryozoans, a fact that has convinced the senior author for more than forty years of the close connection of the two groups. The only other alternative would be the assumption of far-reaching convergent development of the interior structure and general habitus of the two groups, an assumption that loses force in the light of the other similar structures.

5. *GRAPTOLITES MORE PRIMITIVE BRANCH THAN BRYOZOANS PROPER*

From the preceding statements it would appear that the graptolites represent a more primitive branch of the phylum than the bryozoans proper. This is in full accordance with the geologic range of the two: the graptolites appear almost abruptly in the Upper Cambrian, apparently as soon as they had discovered the protection of a chitinous periderm; and the strongly calcareous bryozoans in the lower Ordovician. Ctenostomata that excavate their host, like *Rhopalonaria*, existed already in Ozarkian time. The junior author has in press an article on Cambrian graptolites of Wisconsin and in manuscript others on graptolites from

FIGURE 6.—*Portion of Rhabdosome, oblique frontal View, of Climacograptus typicalis, Hall*

Specimen is from the Viola limestone near Bromide, Oklahoma, showing paired muscle scars. × 6.

Minnesota, the Black Hills and Tennessee. It is significant that these faunules contain but the most primitive sessile genera of the Dendroidea, as notably *Dendrograptus* and *Callograptus* and a new genus *Haplograptus*, in which the rhabdosome consists of a few, irregularly bent tubular thecæ, the most primitive form possible, unless *Protistograptus* McLearn of the Ordovician represents but an overgrown sicula.

We come now to new observations on the muscular system of the graptolites that seem to shed important light on their taxonomic position.

6. *MUSCULAR SYSTEM OF GRAPTOLITES*

There occur in the Viola limestone of Oklahoma specimens of *Climacograptus typicalis* Hall and *Glossograptus quadrimucronatus*, in which the thin black carbonaceous test of the graptolite is removed either by slight weathering or by adhering to the other side of the fractured rock. This remarkable mode of preservation reveals in the finest detail the characters of the interior of the test. The specimens are compressed enough to bring, in the frontal view, the outer (ventral) distal walls of the thecæ and the apertural slits into one plane. In such specimens (see figure 6) series of pairs of minute circular depressions, often with fragments of the black test preserved in them, are seen. One set of these transversal pairs of depressions is found in the middle of the frontal wall, another in the back of the aperture, and a possible third set, less distinct, on the sidewall of the graptolite (see figure 7).

These circular depressions are too small to represent the interior or budding apertures of the thecæ, which are sometimes seen in compressed specimens. Those could not appear in pairs, but only as single impressions, of semi-oval form in *Climacograptus* (see Wiman's sections, 1896, plate 10, figure 4) similar to the apertural impressions seen in the specimen. The only other [4] inference is then, as far as the writers can judge, that these paired small impressions are muscle scars on the inside of the test, one pair on the inside of the frontal distal wall, another pair on the inside of the theca at the level of the aperture of the mother-theca (see diagram, text-figure 8).

FIGURE 7.—*Climacograptus parvus, Hall*
Specimen is from Normanskill shale at Mount Merino, New York. Shows gastral attachment muscles on sides of thecæ. × 7.

Granted that these circular scars mark the attachment places of muscles or tendons—and we can not imagine at present any other explanation of these impressions—they offer an important clue as to the taxonomic position of these graptolites.

It is obvious at once that these three pairs of subcircular muscle scars are in no manner correlatable with the muscle-system of any of the Cnidaria; for the Hydrozoans, to which the graptolites are currently referred, possess only a layer of unstriped muscle-fibers between the ectoderm and mesogloea in the tentacles and the manubrium and these muscle-fibers are not attached to the hydrotheca or able to leave attachment scars. In the corals (Actinozoa) in which stronger muscles are developed, aside from the sphincter, which encircles the body and is therefore not of importance here, all muscles form fibrous bands, located within the mesentery (the longitudinal or retractor muscle, the parietal muscle and the transversal muscle). If these could leave attachment scars, the latter would have to appear as longitudinal lines along the wall (transversal muscles and upper part of parietal muscle) and as radiating lines in the base (longitudinal muscle and lower part of parietal muscle).

[4] As in the hydrozoans the ectoderm of the polyp withdraws from the chitinous theca, after the latter is fully formed, and maintains connection only at intervals with it, it could be surmised that the apparent scars indicate these places where connection was maintained; but this is very improbable for the reason that these patches of adhesion are always very irregular (Parker and Haswell, p. 132).

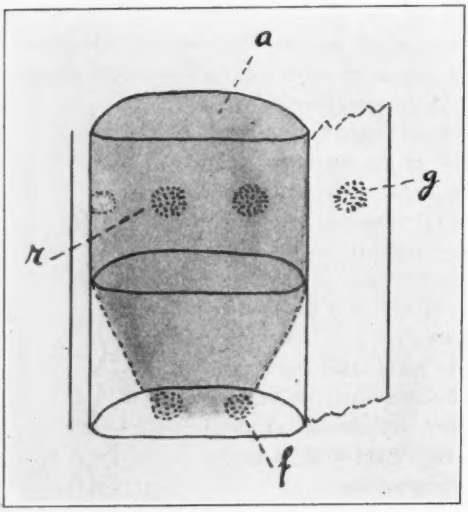

FIGURE 8.—*Diagram of Muscle-scars of One Theca of Climacograptus*

r, retractor muscles; *g*, gastral attachment muscles; *f*, funiculus; *a*, aperture.

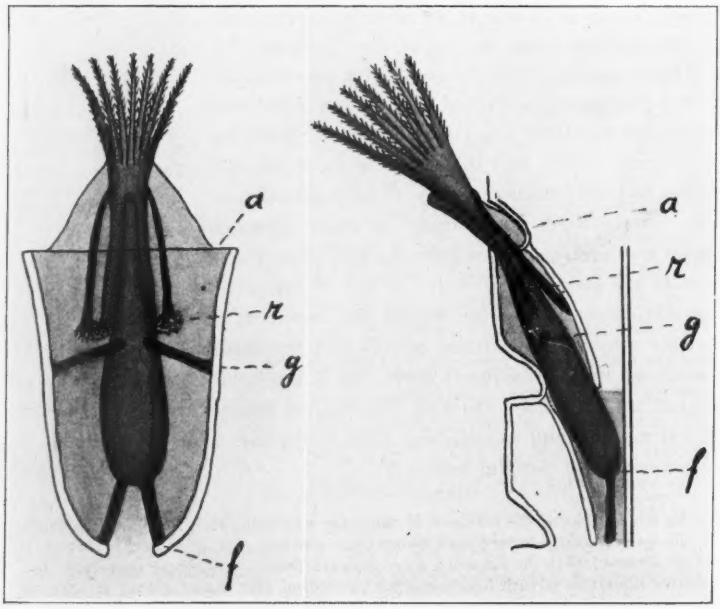

FIGURE 9. — *Restoration of Graptolite-zooid*

Muscles black. *a*, aperture.

FIGURE 10.—*Side View of Same*

Muscles as in figure 8.

While the muscle-scars of the graptolites can not be brought into harmony with the muscles of the Cnidaria, they agree quite strikingly with those prevailing in the Bryozoa. In the latter, more specifically the Ectoprocta, well developed muscles are located in the coelome, or in the cavity interposed between the enteron and the body-wall and as the latter is closely and permanently attached to the wall of the zooecium, their attachment places are recognizable on the inside of the wall. These pairs of muscles are the parieto-vaginal muscle-bands passing to the introvert from the body-wall and serving to retract the introvert and tentacles (*r*, retractor of diagrams), the pair of more slender muscles passing from the body-wall to the stomach and acting as retractors of the alimentary canal when the introvert is drawn back (*g* of diagrams) and finally the funiculus, a large double strand passing from the proximal or aboral end of the alimentary canal to the aboral wall of the zooecium. Of these the first pair is attached laterally to frontally in the oral portion of the coelome, the second pair is attached also in the oral portion posteriorly to the stomach and passes sideways to near and posteriorly of the attachment of the first pair of muscles. The funicles (*f*) finally pass backward from the stomach to the aboral wall of the zooecium. In the graptolite the first pair is seen on the posterior wall of the zooecium,[5] the second pair on the lateral wall (only one of the pair is seen, the other lateral wall being hidden behind the specimen) and the third appears in the apertural cleft.

7. *OOECIA*

A most significant observation was made in a form of the rich graptolite fauna discovered by the senior author and Mr. R. D. Mesler in the Ottosee shale near Knoxville, Tennessee. This graptolite (*Marsipograptus bullatus,* M.S. name) has the habitus of a *Desmograptus,* but is provided with hemispherical and even subspherical swellings or bags attached to the thecæ. In several cases they clearly show a marginal ring and a circular area, sometimes lighter, possibly an opening. These bodies are set off from the rest of the rhabdosome by their darker color indicating a more substantial wall. The senior author, in observing these appendages in the type specimen, unhesitatingly identified them as "ooecia" on the label, and indeed they suggest these brood-pouches of the

[5] As the anterior and posterior walls of each theca are compressed into one plane in the specimen, a thin film separating the two series of thecæ, it is difficult to decide to which wall the muscles were attached. The fact that these muscle-scars appear as depressions, seems to us to indicate that it is the impression of the posterior wall with the muscle-scars that is seen.

FIGURE 11.—*Marsipograptus bullatus, MS. Name, with Ooecia*
From the Ottosee shale, near Knoxville, Tennessee. × 4.

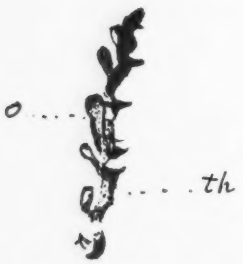

FIGURE 12.—*Ptilograptus sparsus, MS. Name, with Ooecia*
From the Ottosee shale, near Knoxville, Tennessee. × 4.

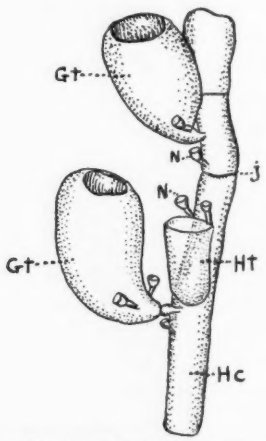

FIGURE 13.—*Part of the Hydrocladium of a dried Specimen of Plumularia profunda* (after Nutting)
Cambridge Natural History, volume (figure 195) to show the structural differences from that of *Ptilograptus*. *Gt, Gonotheca; Ht,* hydrotheca; *Hc,* the stem of the hydrocladium with joints (*j*); *N, nematophores.*

bryozoans by their position and form more than any organ, especially the gonothecæ of the Hydroid Coelenterates.

In studying the Ottosee material another observation was made that has a possible bearing on the bryozoan nature of the graptolites. A number of specimens of a dendroid graptolite, referable to Ptilograptus exhibit oval to club-shaped appendages projecting from the sides of the thecæ and suggesting reproductive bodies. In one exceedingly well preserved specimen the apertures of the thecæ are arranged on one side of the branch and each theca bears a club-shaped appendage, arising laterally on alternating sides (top and bottom in the compressed specimen) near the middle or base of the theca. In position and arrangement they therefore correspond exactly to the "bithecæ," as described by Bulman (1925) for Dictyonema, and these appendages may be extended and dilated bithecæ. If the latter are reproductive thecæ, as is generally assumed, the appendages here described are possibly a further development of the same. They may be termed either gonothecæ or ooecia according to the reference of these graptolites to the Hydrozoans or Bryozoans. Their similarity to ooecia is certainly striking and the fact that the bodies are closed (or nearly closed) indicates that they most probably served as brood-pouches (see below). It is also to be observed that they do not rise from the nemacaulus as do the gonothecæ of the Hydroid Coelenterates (especially the Calyptoblastea), but from the thecæ, as the ooecia do.[6]

Opposing Evidence

Against these observations in Dendroidea, suggesting relationship of the majority of the graptolites to the bryozoans stand some others made by the junior author (1895, 1904) in Graptoloidea that at that time strongly indicated to him the Cnidarian nature of the graptolites. Notably among these are a float or pneumatocyst and a ring of gonangia surrounding the central disk of species of *Diplograptus* and *Lasiograptus*. In appraising these characters, it is to be remembered that they are seen on the synrhabdosomes of axonophorous Graptoloidea, which surely had already traveled far from the primitive ancestral Dendroidea and were highly specialized for a floating habit. It is therefore probable that these features are

[6] We are here leaving out of consideration the more complicated structures found by Wiman in *Dictyonema rarum*, where he distinguishes hydrothecæ with nourishing individuals, "gonangia" and budding individuals. Bulman (1925) has since found a somewhat simpler condition in *D. flabelliforme*, where he finds hydrothecæ and bithecæ; the latter are entirely external while the "gonangia" of Wiman are very largely internal and may represent a later and more complex condition.

new acquisitions, attained independently through their specialization to a floating mode of life, the pneumatocyst being an entirely new organ and the ring of basal gonangia a consequence of the strict radial symmetry of the rhabdosome, forced upon the floating colonies by the necessity of keeping an even keel.

Another problematic feature are the small bithecæ found in nearly all Dendroidea on alternating sides of the thecæ. If these should be recognized as nematocalyces that contained the nematophores of Hydroid Coelenterates, the reference of the graptolites to the Hydrozoa would be much strengthened. On the other hand, their form, arrangement and the substantial character of their tests and the appearance of closed or nearly closed appendages in connection with them in *Ptilograptus,* as described above, is more indicative of the nature of an early development of ovicells or ooecia.

If the graptolites, with the few exceptions noted in the first chapter, prove to be as we believe, more closely related to the Bryozoans than to the Hydrozoans, they would have to be considered as an order of that class that if it is not itself the ancestral stock of the Bryozoa then an order that early separated from the ancestral stock and developed independently, especially after advancing from the Dendroidea to the Graptoloidea.

The authors are aware that a mass of details had to be left out to keep this paper within reasonable bounds and that therefore some statements may appear too generalized. The present paper is therefore offered merely as a preliminary statement to invite discussion and presentation of related facts by other students of the puzzling graptolites.

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DINWOODY GLACIERS, WIND RIVER MOUNTAINS, WYOMING; WITH A BRIEF SURVEY OF EXISTING GLACIERS IN THE UNITED STATES[1]

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(*Read before the Geological Society December 31, 1930*)

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INTRODUCTION

Of the large number of active glaciers present in the higher mountains of the western United States few are several miles in length, forming parts of rather extensive glacier systems, but most of them are small—not more than 2 or 3 square miles in surface area—and but little, if any, greater in length than in width. Probably most of them are essentially cliff glaciers,[2] and move only very short distances down from the basin of snow accumulation.

Some of the larger systems, such as those of Mount Rainier and Glacier National Park, are now well known, but others, especially the smaller ones in districts which have not been geologically mapped, are but little known except to local hunters and sportsmen. Those of the Wind River Range, including the Dinwoody glaciers here described, have been known for many years, and they are shown on the Fremont Peak topographic sheet of the United States Geological Survey, first printed in 1909. So far as the writers have been able to learn, however, but few geologists have visited these glaciers; for that reason the present article will discuss the salient features of two of the Dinwoody glaciers and indicate the position of the Wind river group, particularly as to relative size, among the active glaciers of the United States.

[1] Manuscript received by the Secretary of the Society January 13, 1931.
[2] W. H. Hobbs: Characteristics of existing glaciers, New York, 1911, p. 54.

The geologist who traverses the Wind River valley northwest from Riverton, Wyoming, has his attention directed toward glacial problems by the large amount of morainic material which has been carried down to the main valley by glaciers of the Wind River system during Pleistocene time. Geologic studies for the United States Engineer Office during the summer of 1930 afforded the writers an opportunity to visit this region and to spend several days in the lower valleys of Dinwoody and Bull Lake creeks, two of the larger streams now draining the northeast slope of the Wind River Range. Here the great thickness and extent of Pleistocene drift deposits and the milky turbidity of the water, especially of Dinwoody Creek, even after passing through several large lakes, aroused their curiosity in regard to existing glaciation. Local rumor pronounced the Dinwoody Glacier "the largest in the United States." Although this claim did not seem justified by the sizes shown on the United States Geological Survey maps, the milkiness of the water of Dinwoody Creek some 20 miles or more from its source indicated a considerable amount of glacial erosion. To observe as much as possible of the glacial activity in this basin, a three-day pack trip was undertaken with the aid of Mr. L. A. Phillips of Burris, Wyoming.

Only the most general and outstanding features were recorded in the course of this short visit, but it is hoped that brief descriptions of these features, supplemented by photographs, may bring this group of glaciers to the attention of others who may wish to undertake more extensive studies of the present and past glaciation of the region.

Brief Survey of existing Glaciers in the United States

No recent or adequate gazetteer of the active glaciers of the United States is known to the writers. Brief descriptions of some of these glaciers were presented by Russell [3] in 1885 and 1904, but many of them were unknown at that time. In the following pages will be listed the size, location, and general character of the more important glacier groups or isolated glaciers or regional importance, but the detailed description of individual glaciers will not be attempted.

The southernmost glaciers in the United States, so far as known, are those in the high crest of the Sierra Nevada between latitude 36° 45′ and 38° north. In this region are more than a score of small glaciers, the largest less than a mile in length. The lowest elevation at which they are

[3] I. C. Russell: Existing glaciers of the United States. U. S. Geol. Survey, Fifth Ann. Rept., 1885, pp. 303-355.
I. C. Russell: Glaciers of North America, Boston, 1904, pp. 32-70.

found is about 11,000 feet above sealevel.[4] These glaciers were first recognized and described in 1871 by John Muir.[5] In the decade that followed, they were seen by Whitney, King, Le Conte, and others, and considerable controversy arose as to whether they could properly be called true glaciers.[6]

Northward the next glaciers are found on Mount Shasta, where Whitney, Bolam, Hotlum, Wintun, and Konwakiton glaciers are clustered round the summit of the cone, most of them on its northern half. The longest of these is not more than 2 miles in length, in the direction of movement, and the lowest elevation reached is about 8,300 feet. These Mount Shasta glaciers were first described by Clarence King in 1871.[7] According to Hodge, they have a combined surface area of 2,005 acres (3.13 square miles);[8] the largest, Hotlum, has a surface area of 965 acres (1.51 square miles). (See figure 1.)

Northward from Mount Shasta, in the Cascade Range of Oregon and Washington, occur a considerable number of large groups of glaciers which owe their existence to heavy snow precipitation in combination with the height of the mountains. Except in the northern part of the area the principal glaciers are arranged in great radial clusters on the flanks of the magnificent volcanic cones, Mounts Jefferson, Hood, Adams, Rainier, and Baker, which rise far above the general level of the Cascade Range.

First in order of this series is the group of 17 glaciers arranged around the summits of the Three Sisters—remnants, according to Hodge,[9] of the single ancient cone of Mount Multnomah. The longest of these glaciers is about 1½ miles long and has a surface area of nearly three-fourths of a square mile. The area of the entire group is 2,257 acres (3.53 square miles), and the lowest elevation reached by the ice is about 7,000 feet.

About 80 miles north of the Three Sisters is the glacier system of Mount Hood, with a total area, according to Hodge, of 1828 acres (2.86 square miles). On the United States Geological Survey map of the area are named eight glaciers, of which the longest is slightly over 2 miles in length. The area of the largest is estimated from the map at slightly over 1 square mile, and the lowest elevation reached is about 5,700 feet. The

[4] I. C. Russell: Existing glaciers of the United States, pp. 314-326.
I. C. Russell: Glaciers of North America, pp. 37-52.
[5] John Muir: Living glaciers of California. Harper's Magazine, vol. 51, 1875, p. 769.
[6] I. C. Russell: Glaciers of North America, pp. 50-52.
[7] I. C. Russell: Glaciers of North America, pp. 329-334.
Clarence King: Amer. Jour. Sci., vol. 1, 1871, p. 157.
[8] E. T. Hodge: Mount Multnomah, University of Oregon, 1925, p. 71.
[9] E. T. Hodge: Op. cit., pp. 1-2.

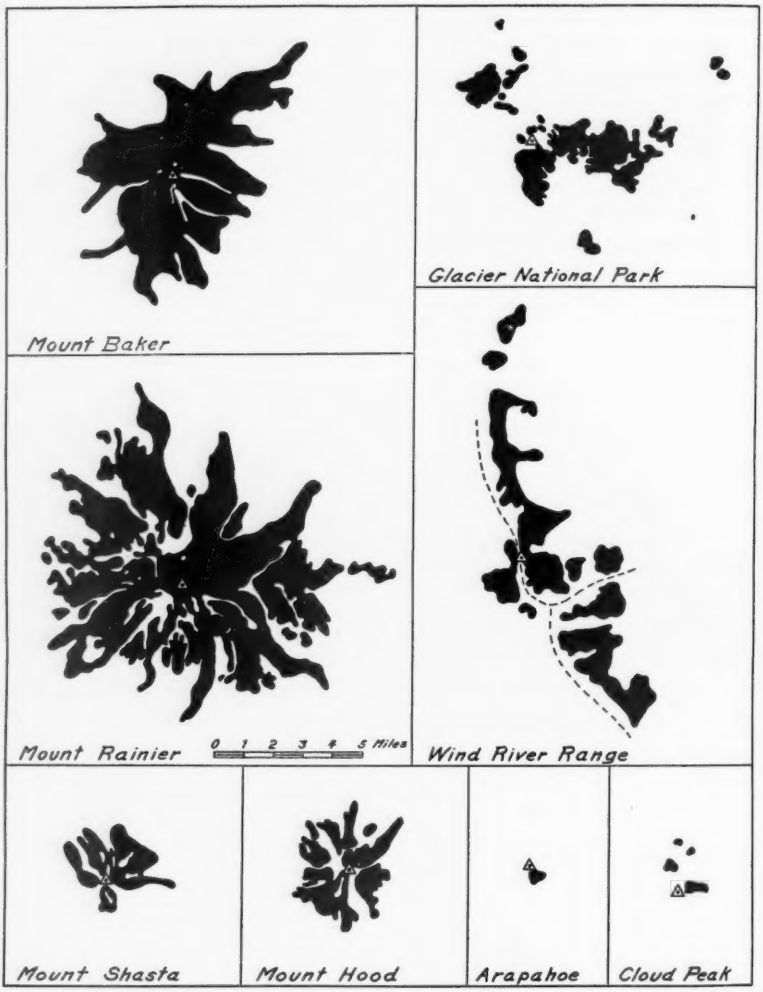

FIGURE 1.—*Sketch Map showing comparative Sizes of important Glaciers and glacier Groups of the western United States*

Scale is the same for all groups. Data from U. S. Geological Survey topographic maps.

Mount Hood glaciers were first described by Arnold Hague in a contribution to the previously cited paper by Clarence King.[10]

All the glacier systems of the northwest United States are surpassed in size and grandeur by the cluster which has incised the slopes of Mount Rainier and which, like a great octopus, stretches in every direction with nearly equal arms. This group consists of 25 glaciers as named on the Mount Rainier topographic sheet, the total area of ice being about 45 square miles.[11] The longest are about 6 miles in length, and the lowest point reached by the ice is about 3,350 feet above sealevel and more than 11,000 feet below the summit of Rainier. The first account of glaciers on Mount Rainier was presented by S. F. Emmons in 1871 in a contribution to the summary compiled by King.[12] The existence of glaciers here had previously been reported by A. V. Kautz, who attempted the ascent of Mount Rainier in 1857.[13]

Large glacier groups are known on Mount Jefferson, Diamond Peak, Mount Saint Helens, Mount Baker, Mount Shuksan, and Glacier Peak, and numerous individual glaciers of 2 or 3 square miles in extent are present in the Cascade Range of north central Washington. The largest group, aside from those already described, appears to be that on Mount Baker, which has a surface area of 24.7 square miles and is a compact and nearly unbroken ice-mass 10 miles in length and about 6 miles in width. The lowest elevation reached is 3,200 feet, and the longest ice-tongue is about 5 miles in length.

No reliable estimate of the total area covered by existing glaciers in the Sierra and Cascade mountain ranges can be made until these are more completely mapped, but it is clear that the area is well over 100 square miles and possibly more than 150 square miles.

In the report by Russell on existing glaciers of the United States, it is indicative that Jeff Davis Peak, one of the high mountains in the Great Basin, carries a body of neve which may approach the condition of a glacier.[14] However, no further reference to this peak has been found in the literature, and it appears probable that no glacial action is now going on in the Great Basin region.

The southernmost glaciers of the Rocky Mountain region are in Colorado. These have been described by Henderson, who summarizes the

[10] I. C. Russell: Glaciers of North America, p. 68.
[11] F. E. Matthes: Mount Rainier National Park topographic map, text, 1916.
[12] Clarence King: Amer. Jour. Sci., vol. 1, 1871, p. 161.
[13] I. C. Russell: Glaciers of North America, pp. 62-63.
[14] I. C. Russell: Existing glaciers of the United States, pp. 342-343.

knowledge of Colorado glaciers in an excellent paper published in 1910.[15] He lists Arapahoe, Isabel, Fair, Hallett, Andrew, Tyndall, Sprague, and the Sierra Blanc glaciers. Some of these, not visited by Henderson, may prove not to be true glaciers. He mentions several other ice-masses, and devotes a number of pages to discussion of the problem of discriminating true glaciers from stationary masses of neve. The most important undoubted glacier of the group is Arapahoe, located on the eastern side of the Front Range in latitude 40° 02′ north. This glacier is less than half a mile long and about a third of a mile wide, and has a surface area of about one-fourth of a square mile. It shows all the characteristic features of true glaciers and its rate of motion near the center is about 30 feet per annum.

Existing glaciers in Wyoming are the Wind River group, the Teton glaciers, the Sunlight Glacier, the Cloud Peak glaciers and the DuNoir Glacier. The four Cloud Peak glaciers have a combined surface area of about half a square mile. The largest is about three-fourths of a mile long and three-eights of a mile wide, with an erea of not more than a quarter of a square mile. The lowest elevation reached by the ice is about 11,250 feet.

DuNoir Glacier is about one-fourth of a mile long in the direction of motion and has an area of about one-fifth of a square mile. On the Younts Peak topographic sheet, it is shown at the head of DuNoir Creek and about 25 miles northwest of Dubois, Wyoming. Sunlight Glacier, in latitude 44° 37′ north, is at the head of Sulphur Creek, tributary to Sunlight Creek and Clarks Fork and about 11 miles east of the east margin of Yellowstone National Park. This glacier is described by Hague[16] as small, but its dimensions are not given. According to local information obtained by the writers, it is not more than half a mile in length.

A number of small ice bodies are perched on the steep eastern slopes of the several high peaks of the Tetons in western Wyoming, where they can be plainly seen from the Jackson Hole country. Several authorities agree that these are true glaciers, and from points below they have that appearance.[17] None of these is more than quarter of a mile in length or more than a few acres in extent.

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[15] Junius Henderson: Extinct and existing glaciers of Colorado. University of Colorado Studies, vol. 8, no. 1, 1910, pp. 33-76.

[16] Arnold Hague: Absaroka folio. U. S. Geol. Survey, 1899.

[17] Arnold Hague: Yellowstone National Park folio. U. S. Geol. Survey, 1899.

W. H. Holmes: Quoted by I. C. Russell: Existing glaciers of the United States. U. S. Geol. Survey, Fifth Ann. Rept., p. 346, 1885.

The Wind River glaciers are by far the largest in the Rocky Mountains south of Glacier National Park, and in continuity of ice along the crest of the range they probably exceed even those of northern Montana. They extend with few breaks for about 15 miles along the Wind River crest from Knifepoint Mountain to Downs Mountain and have a total surface area of 15.14 square miles. This group, which includes the two Dinwoody glaciers—the principal subject of this paper—will be described more fully later in this article (see figure 1).

In Montana, glaciers still exist in the Crazy Mountains,[18] at the head of Rosebud Canyon, northeast of Yellowstone Park,[19] and in Glacier National Park. Doubtless a few other small glaciers will be discovered.

In Glacier National Park there are more than 80 distinct glaciers, of which 9 have surface areas of 1 square mile or more, and 13 others exceed one-fourth of a square mile in area. The total area of ice is estimated at not more than 25 square miles, distributed over a territory 60 miles long by about 20 miles broad. The largest group of glaciers in the park is that consisting of Blackfeet, Harrison, and Pumpelly glaciers, with Sperry Glacier about 3 miles to the northwest. This group consists of approximately 7 square miles of ice; it is shown in comparison with others in figure 1. The next largest cluster in the park is in the vicinity of Kintla Peak and consists of Kintla and Agassiz glaciers, with a combined area of about 3 square miles. The lowest elevation reached by the ice is about 6,000 feet.

Features of the Dinwoody Glaciers

The Wind River Mountains extend from southeast to northwest a distance of more than 100 miles in west central Wyoming, forming the divide between the headwaters of Green River of the Colorado system and the southwestern branches of Wind River of the Missouri-Mississippi system. Throughout much of its length the range rises to over 12,000 feet, and in the district under discussion, there are more than a dozen peaks rising to more than 13,000 feet.

In the vicinity of the Wind River glaciers, the Wind River Range is about 25 miles wide at the 10,000-foot contour and the central upland area is very rugged, the ancient plateau having been deeply and irregularly dissected by streams and by Pleistocene glaciers. Great numbers of U-shaped valleys, hanging valleys, cirques, and ice-gouged and moraine-

[18] G. R. Mansfield: Glaciation in the Crazy Mountains of Montana. Bull. Geol. Soc. Amer., vol. 19, 1907, pp. 561-562.

[19] J. E. Haynes: Haynes guide (Yellowstone National Park), 1930, p. 135.

dammed lakes testify to the extent and vigor of former glaciers which extended for more than 20 miles down the valley of Dinwoody Creek. As shown on the Fremont Peak topographic sheet, the region is remarkable, even among those formerly the scenes of mountain glaciation, for the great number of lakes, especially the tiny "inkwell" lakes found by hundreds on the plateau southwest of Fremont and Gannett Peaks. The physiographic features of the range have been described by Westgate and Branson.[20]

The existence of active glaciers in the Wind River Range has been known for more than 50 years. The first published reference is contained in a preliminary report of the Geological Survey of the Territories for 1878, in charge of F. V. Hayden. Russell quotes an account of the discovery of these glaciers by W. H. Holmes, geologist and artist of the Hayden survey.[21] They have been briefly mentioned by several other writers.[22]

The present Wind River glaciers extend for about 15 miles along the northeastern side of the divide. The continuity of the ice mass is broken in only four places, the longest continuous mass being about 8 miles and another about 4 miles in length. Southwest of Gannett Peak there are three glaciers on the west side of the divide. The entire system may be divided into three parts, according to drainage. The northernmost 10 miles of the glaciers on the east slope discharge water into Dinwoody Creek and thence through Wind, Bighorn, and Yellowstone rivers into the Missouri. The remainder of the east slope glaciers drain to the same system through Bull Lake Creek. The glaciers on the west slope are tributary to Green River, two of them directly and one through Titcomb Lakes and a branch of Fremont Creek. The area of Dinwoody glaciers is 8.23-square miles, of the Bull Lake glaciers 5.33 square miles, and of the Green River glaciers 1.58 square miles. The area of ice draining to Dinwoody Creek is larger than that draining to any one headwater stream in the Rocky Mountains south of the Canadian boundary.

The size and form of the three large glaciers which surround Gannett Park are shown in figure 2. Gannett Peak (13,785 feet) is the highest

[20] L. G. Westgate and E. B. Branson: The Later Cenozoic history of the Wind River Mountains, Wyoming. Jour. Geol., vol. 21, 1913, pp. 142-159.

[21] I. C. Russell: Existing Glaciers of the United States, pp. 344-346.

[22] T. B. Comstock: Some peculiarities of the local drift in the Rocky Mountains. Science, vol. 20, 1886, pp. 925-926.

Junius Henderson: Extinct and existing glaciers of Colorado. Univ. of Colorado Studies, vol. 8, no. 1, 1910, p. 50.

U. S. Geol. Survey topographic map, Fremont Peak Quadrangle, Scale 1/125,000, 1909.

L. G. Westgate and E. B. Branson: Op. cit., p. 157.

point in Wyoming and was named for Henry Gannett, former Chief Geographer of the United States Geological Survey. It is here proposed that the three glaciers indicated be named North Gannett, East Gannett, and West Gannett glaciers respectively, in further recognition of the distinguished service rendered by Doctor Gannett to his profession. North

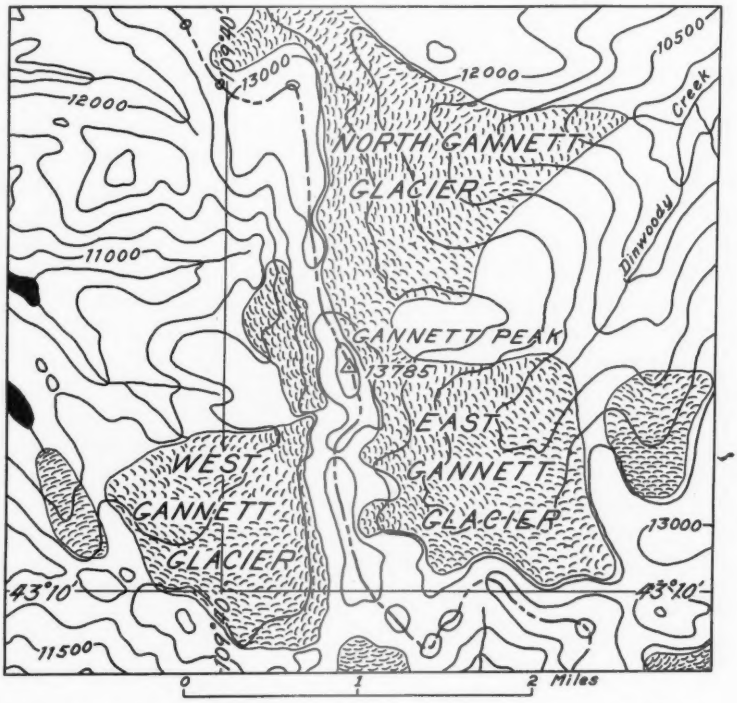

FIGURE 2.—*North Gannett, East Gannett, and West Gannett Glaciers in Relation to Gannett Peak and the Continental Divide*

The Continental Divide follows the crest of the Wind River Range. The map was redrawn from Freemont Peak topographic map of U. S. Geological Survey.

and East Gannett glaciers were visited by the writers during the past summer and their chief features are described below.

The general relationships of the three Gannett glaciers to Gannett Peak are shown in figure 2. They are drained by the southernmost and longest branch of Dinwoody Creek which flows about 11 miles in a direction

about 25 degrees east of north gathering other glacier-draining branches and then turns more sharply to the east for a course of several miles farther before emerging from the mountains and entering Wind River. Throughout its course, Dinwoody Creek Valley is replete with the features resulting from Pleistocene glaciation. Many miles of the upper course are typically U-shaped and the stream receives the waters of many ice-gouged lakes through valleys which are notably "hanging" with reference to the main valley. Roches moutonnees and scoured and striated surfaces are well preserved on the valley walls at elevations of several hundred feet above the stream.

In the lower part of the valley where the Deadwood formation has been deeply gouged away and where the more resistant Bighorn limestone still forms a rock barrier across the valley, there are many places where striated surfaces bevel the mountain-facing edges of the limestone strata and indicate movement of the ice up slopes as steep as 30 degrees. In the limestone barrier some most interesting physiographic episodes have been worked out which resulted in a natural tunnel several hundred feet long and a deeply incised post-glacial gorge through both of which the entire drainage of the Dinwoody glacier system passes.

Still farther downstream is a series of large, moraine-dammed lakes which serve in some measure to clarify the waters of the Dinwoody system. However, the total amount of fine rock debris from the several glaciers is so great that the milkiness of the water is still very evident at the crossing of U. S. Highway 87.

East Gannett Glacier is of palmate form, the several fingers being separate snowfields lodged in subordinate cirques which are separated by bare rock crags extending eastward from the main divide (plate 16, figures 1 and 3). From these several snowfields, the ice moves in great converging curves to form a short, narrow tongue which advances only a few rods before it is dissipated by melting and forms a compact, chucky terminal moraine. No means is at hand for making an accurate estimate of the thickness of this glacier, but from the steepness of the frontal slope for considerable distances and the probable configuration of the compound cirque in which it lies, it is thought that the thickness of the ice may, in places, reach 300 or 400 feet.

There is no evidence of a rock spur extending out under the central portion of East Gannett as is the case in North Gannett (plate 16, figure 4). Each of the snowfields lies at a steep angle in the lee of the sharp crested ridge which forms the divide in the vicinity of Gannett Peak.

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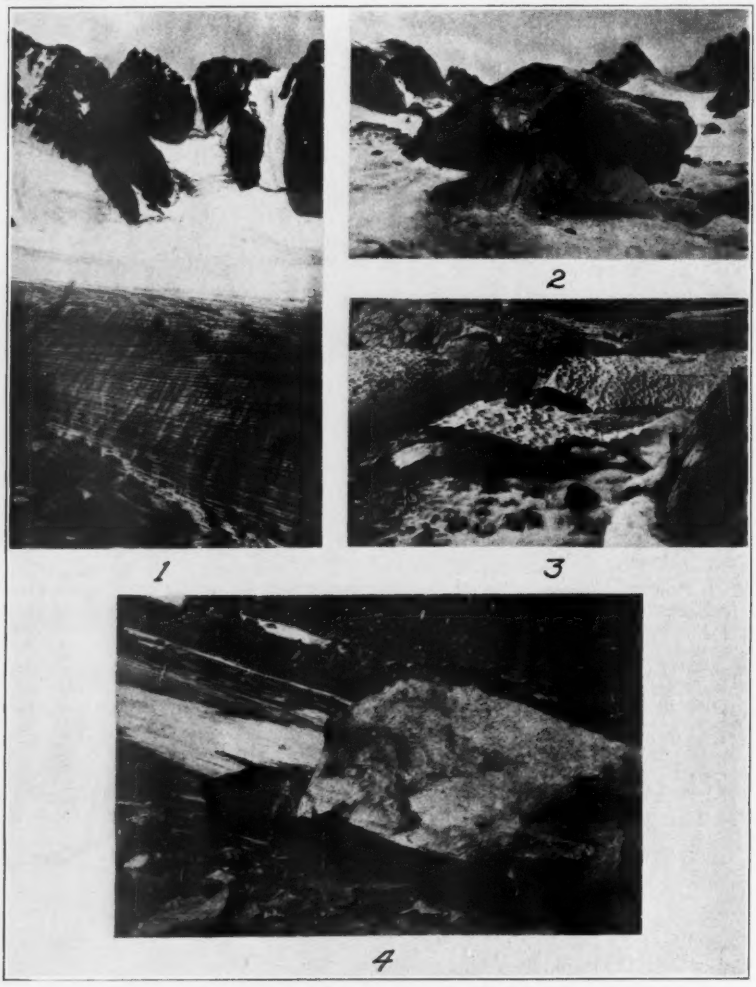
GANNETT GLACIERS

1. View of East Gannett Glacier from its terminal moraine. Shows morainic material on its lower surface, the serrate crest of the range, and several of the feeder cirques which furnish ice to the main glacier. 2. View of southern lobe of North Gannett Glacier from moraine. 3. A closer view of East Gannett Glacier and Gannett Peak (center) and of the mid-slope surface of the glacier with its small medial moraines. 4. View of front of North Gannett Glacier showing its lobes and the high serrate crest of the range. Gannett Peak lies slightly to the left of the picture.



EAST GANNETT GLACIER

1. View across the upper portion of the southeastern lobe of East Gannett Glacier. The line of an irregular bergschrund can be seen in the distance. The near view shows the weathered edge of the ice where three sets of structure planes can be distinguished: curved shear surfaces, accumulation bedding, and nearly vertical joints of obscure significance. 2. A glacier table on East Gannett Glacier. 3. A small and nearly collapsed snow bridge over east branch of Dinwoody Creek. 4. Large block of rock on lower end of East Gannett Glacier. Around it is a deep annular well apparently due to the reflection and radiation from the Rock.

From a distance the trace of a bergschrund is plainly seen at the foot of each snowfield. At the time of the writers' visit, the headward portion of the surface of the glacier was lightly covered with snow which in places extended well down toward the point of general convergence. Where the snow was missing and over the portions of the merged ice-stream which were topographically lowest, were many small streams of water in channels mostly only a few inches deep and wide. A few of these were wider and deeper, occupying tortuous and undercut channels that were somewhat difficult to cross except at selected points. In the main very little of the water found its way through the ice until the lower and steeper part of the frontal slope was reached.

Viewed as a whole, the confluent motion of the ice was clearly indicated by small medial moraines or discontinuous lines of debris, though many parts of the ice were almost entirely free from rock fragments (plate 16, figure 3). The debris on the ice ranged from sand-sized particles to blocks 50 feet in length. Blocks more than 4 or 5 inches in thickness were commonly either perched on ice-columns a few inches high or had recently fallen from such a position (plate 17, figure 2). Much of the finer debris was embedded in pits in the clear ice, the surface being drenched with flowing water. A few rather large and characteristic glacier tables were seen.

The largest rock mass seen was estimated at 60 by 40 feet in horizontal dimension and 25 feet in thickness. It was near the lowest part of the exposed ice. Its position was unusual in that its base was embedded perhaps 12 or 15 feet below the normal surface of the ice and it was surrounded by an annular well about 10 feet wide. Apparently the reflected heat of the sun, together with the capacity of the great block for heat storage over periods longer than days had caused it to melt away downward in a process contrary to that of moderate sized blocks (plate 17, figure 4).

Approaching the front of East Gannett from downstream one views a talus slope of large angular blocks somewhat more than a hundred feet in height, parts of which are drifted over by snowbanks lying at the same angle (plate 16, figure 1). Reaching its crest one sees several hundred feet of debris-covered surface stretching before him. Close examination of low places in the pile shows that the whole mass is underlain by ice and is probably subject to movement practically out to the frontal talus. At low points in the ice surface, where there is a strong flow of water in channels and surface water trickles down over mud and stone-laden surfaces, there is constant erosional and transport activity. Large and small stones

are slowly undermined to fall into the channels and are then swept downstream until they lodge behind some temporary jam of similar material.

The entire mass of East Gannett, so far as the writers were able to observe, is rather notably free from crevassing. Surface streams flow for long distances without interruption by transverse crevasses, and substantially all the fissures and openings by which water goes below the ice at the lower end appeared to the writers to have been developed essentially by melting action without fracturing. The lower part of the exposed ice showed a rather uniform slope of about 15 degrees and this changed fairly abruptly several hundred feet upstream to a slope of about 11 degrees which continued with little change to the bergschrund.

Along the southern margin of East Gannett is a quite continuous lateral moraine which continues along the side of the ice with slightly diminishing height nearly to the bergschrund. Along the side of the ice adjacent to this moraine is a side slope of 15 or 18 degrees which is rather sharply marked off from the smooth longitudinal top slope of the ice. A systematically laminated structure may be seen both in this exposed side slope and in the top slope here and at other points (plate 17, figure 1). Perhaps the most prominent structure consists of curved, upturned planes which in the lower ice are nearly horizontal but which emerge on the top surface with an upstream dip of 30 to 40 degrees. The trace of these planes on the upper surface is convex downstream, apparently indicating more rapid motion near the center of the ice. In places near the center of the glacier, other planes of lamination were noted which were essentially vertical and had a trend parallel to the direction of motion. The origin of these was not apparent.

North Gannett Glacier is also of somewhat palmate form, the two most prominent fingers extending northward and southward, the subordinate appendages westward (figure 2). A southern extension joins the ice-mass to East Gannett Glacier through a high divide adjacent to the upper eastern slope of Gannett Peak. The northern extension lies in another high divide and connects with the group of small unnamed glaciers near Klondike Lake several miles to the northward. The shorter fingers of ice originate in a series of subordinate cirques separated by short rock ridges along the precipitous eastern side of the rugged continental divide. Coalescence of these smaller masses as they move outward fills a large compound cirque from which the ice advances only a short distance down the valley. The glacier terminates at this point with a small terminal and lateral moraine (plate 16, figure 2), only the latter covering any portion of the ice. No accurate estimate of the thickness of the ice in this glacier

can be made from available data, but judging from the relationship of the adjacent topography to the ice-mass and from the contour of the ice surface, a thickness of 500 to 600 feet seems most probable.

The lower face of the glacier is broken by a narrow rock ridge about 300 feet high which rises a short distance above the lower surface (plate 16, figure 4), dividing the glacier terminus into north and south lobes. The ice face is steep with a slope approximating 35 degrees for the first 300 feet of height, then gradually flattening above on a narrow bench to a slope of about 12 degrees. A small lateral moraine with an average height of 100 feet and a length of some 300 yards below the ice lies on the south side of the valley.

The narrow bench at the top of the initial steep slope of ice extends westward only about 300 yards, but continues northward into the divide, connecting this glacier with the ice-masses near Klondike Lake. The nearer portion of this part of the glacier is modified by at least three small cirques whose ice-masses join that from the divide in broad sweeping curves traced upon the surface by narrow lines of rock debris. This eastward movement from the cirques has resulted in the accumulation of debris along the eastern valley wall and the formation of a short lateral moraine about 50 feet high (plate 16, figure 4).

A steep slope averaging 25 degrees separates this first bench from the gently sloping surface of the main mass of the glacier which fills the compound cirque to the west. This steeper portion is very rough, its surface broken by closely spaced crevasses which average several feet in width and attain lengths of almost a mile. These crevasses slope upward toward the continental divide and are convex toward the direction of ice movement, indicating differential movement in the ice-mass. Many are at least partially filled with snow, and others act as channels for the many small streams eroding the surface of the ice.

The major portion of the glacier resembles a vast pocket of ice, sloping eastward in a series of benches and steep slopes, rising steeply on three sides to meet the steep northeast flank of Gannett Peak and the almost vertical walls of the cirques. At the time of the writers' visit the upper portion was almost entirely covered with snow which, however, did not entirely hide evidences of extensive crevassing in the steeper and higher portions. The bergschrund can be traced along the larger part of the upper periphery of the snow field, but is nowhere prominent.

The motion of the ice in this central portion of the glacier is clearly traced by confluent lines of debris from the dividing ridges between the

subordinate cirques. These indicate that the ice from the small cirques to the northwest moves into the north lobe of the ice front, that from the southern portion of the glacier forming the south lobe. A small hill of rock fragments has collected against the upper end of the dividing rock ridge, indicating that a considerable period of time has elapsed since it was last entirely covered by the ice.

In general the ice surface is surprisingly free from debris. Most of that present on the higher portion of the ice is arranged in long sweeping, sometimes discontinuous curves originating at the bounding ridges of the small cirques. Concentration of this material as the ice enters the restricted upper end of the valley covers most of the surface. The small particles of rock cover this portion of the ice so thickly as to give it a dark appearance when viewed from a distance (plate 16, figure 4). Most of these smaller particles are embedded in the roughened and pitted surface. The debris ranges from these very small particles to irregular blocks 15 feet long and several feet thick. These larger blocks are usually partially embedded in the ice and are surrounded by a narrow annular ring, probably caused by heat radiation from the rock mass. No well defined ice tables were seen. The entire surface of this lower portion of the ice was drenched with water.

Small streams are abundant on this part of the glacier, occupying channels eroded in the ice and flowing in many crevasses. On the higher levels, small streams were noted flowing beneath the fresh snow along the solid ice. Most of these streams join along the lower portion of the ice and flow between the northern wall of the valley and the ice-mass. This stream joins another emerging from beneath the southern lobe several hundred yards below the glacier front and forms the northern headwater branch of Dinwoody Creek.

No mapping was done in the brief time available, and the accompanying map was taken from the United States Geological Survey map made over 20 years ago. From its general relation to the surrounding topography, it is thought that the lower end of North Gannett Glacier is at least a quarter of a mile and possibly as much as half a mile short of the position shown on the map. As nearly as can be judged from the generalized mapping, East Gannett Glacier may not be any shorter than is shown on the map, but it appears somewhat as though its lower tongue were now shrunk more nearly into the central valley trough than is shown on the map and this may indicate a similar shrinkage.

East of East Gannett Glacier there is shown on the map a small independent glacier about three-fourths of a mile wide. This small hanging

cirque was not visited nor its extreme floor viewed from a distance, but enough of its side walls was seen from the spur south of North Gannett Glacier to reveal any such ice-mass as that shown on the map. A few snowbanks were seen on the more sheltered slopes but there was no evidence of a true glacier here and no stream of milky water appeared to be flowing from this basin. From these various observations, it appears that there has been a moderate retreat of the glaciers and a restriction of glacial action in the last two decades in this district.

The remaining glaciers shown in figure 2 were not visited and no data are at hand concerning them. Plans were made for an attempt to learn the rate of motion of the two eastern glaciers, but no measurement could be made during the brief visit described. From the rate of ice melting and the amount of debris which was in process of transport, and the long, distinct lines of morainic material converging from the several intercirque ridges there can be no doubt in the mind of the visitor that these ice-masses are in motion and that they are therefore true glaciers. Indeed the distance of motion from the bergschrund, itself a proof of motion and the sufficiency of motion to bring about a merging of ice streams from several cirques and thence the progress of the merged mass a still greater distance down the slope to the narrowed trough which forms the head of the valley proper, are indications of a force of mobilization far greater than the minimum necessary to produce true glaciers.

These glaciers, and the others which make up the Wind River system, although not of the size and vigor shown by those of the Cascade Range, certainly receive a substantial reserve of snow above that necessary to maintain glacier motion, and in this respect, as a result of the abrupt height and continuity of the Wind River Range, are at least the equal of any others in the Rocky Mountains of the United States.

Though there is abundant evidence of far more extensive glaciation in this region in the past than persists today, the existing glaciers do not appear to have abandoned the chief head cirque by assuming higher cliff positions. With reference to the classification of mountain glaciers described by Hobbs,[23] the two glaciers described by the writers appear to belong to the class of radiating or Alpine glaciers, using the latter term in the specific sense advocated by him. A large decrease of snowfall and much further restriction of ice would result in the formation in both the North and East Gannet basins of a fringe of small ice-masses in the separate cirques which would together in each case constitute a glacier of the horseshoe type as described by Hobbs.

[23] W. H. Hobbs: Characteristics of existing glaciers, New York, 1911, pp. 41-58.

It is thought that other glaciers af the Wind River system, taken into consideration with the various physiographic evidences of the relations of corresponding Pleistocene glaciers, will show similar evidences of progressive decrease of snowfall, not only since Pleistocene time, but also very likely as the current trend of the past few years. Field studies of these comparatively accessible and not too extensive glaciers will yield valuable contributions both to geology and geography, and it is to be hoped that a general examination of the whole group can be undertaken in the near future by some student interested in glaciers and glaciation.

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EARLY SILURIAN FORMATIONS OF SOUTHEASTERN PENNSYLVANIA[1]

BY CHARLES K. SWARTZ AND FRANK M. SWARTZ

(Read before the Society December 28, 1923[2])

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[1] Manuscript received by the Secretary of the Society October 27, 1930.
[2] Bull. Geol. Soc. Amer., vol. 35, pp. 104-105.

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Introduction

Historical review

The problem presented by the nearly barren early Silurian formations of southeastern New York is of long standing. The basal deposits were named the Shawangunk by Mather in 1840.[3] They were long considered to be Medinan in age because of their lithology and their position beneath supposed Niagaran limestone.

Hartnagel subsequently showed that the limestone is not Niagaran but late Silurian Cobleskill,[4] and concluded that the Shawangunk is Salinan. He seems to have based his opinion upon (1) the conditions of overlap in a transgressing sea, (2) the existence of a marked unconformity at its base, indicating the lapse of a long time for folding and erosion since the Ordovician,[5] and the nonfossiliferous character of the strata, suggesting the aridity of the Salina.[6] J. M. Clarke accepted Hartnagel's correlation, fortifying his opinion by the discovery of numerous Eurypterids in the black shale in the Shawangunk which he deemed analogous to the occurrence of Eurypterids in the black Pittsford shale of Salinan age[7] (although the species differ).

The Shawangunk, except for its upper beds, was made Medinan by Schuchert,[8] who based his correlation largely upon the presence in it of *Arthrophycus alleghaniensis*. More recently it was made Clinton by Ulrich, who affirms that *Arthrophycus alleghaniensis* is not confined to Medinan deposits, but ranges into higher beds.[9]

The New York Shawangunk was correlated by Weller and others with the Shawangunk of northern New Jersey,[10] with which it is continuous as far south as Delaware Water Gap.

[3] W. W. Mather: N. Y. Geol. Surv., Fourth Ann. Rept., 1840, pp. 246-255.
[4] C. A. Hartnagel: N. Y. State Mus., Bull. 69, 1903, p. 1109 et seq.
[5] A marked unconformity exists in eastern Pennsylvania beneath the Tuscarora, which lies below well defined Rochester and Clinton faunas, as at Swatara Gap.
[6] C. A. Hartnagel: N. Y. State Mus., Bull. 107, 1907, p. 50.
[7] J. M. Clarke: N. Y. State Mus., Bull. 107, 1907, pp. 295-297, 302.
[8] Charles Schuchert: Bull. Geol. Soc. Amer., vol. 26, 1915, p. 150; vol. 27, 1916, p. 531.
[9] E. O. Ulrich: Md. Geol. Surv., Silurian, 1923, p. 267 and pp. 327-328, footnote.
[10] S. Weller: N. J. Geol. Surv., Paleontology, vol. 3, 1903, p. 54.

In 1923 the senior author presented a paper before the Geological Society of America,[11] the substance of which is more fully elaborated in the present discussion.

RELATION TO MARYLAND SECTIONS

The Maryland Silurian has been studied by Ulrich, Bassler, Prouty, and the senior author, the first two workers describing the ostracoda, the last two the remaining forms. A profuse fauna is found in the Maryland Rochester and pre-Rochester Clinton,[12] permitting of a trustworthy correlation of these beds with the corresponding formations of western New York.

The Maryland deposits are continuous with those of Pennsylvania, New Jersey, and eastern New York, having evidently been deposited in the same basin. It was believed therefore that a study of closely placed sections might enable us to correlate the deposits of eastern and western New York and of the entire area. We accordingly studied a series of sections extending from western Maryland to the Delaware River and thence to New York.

PLAN OF PRESENTATION

In presenting the results of this study we will first consider certain critical horizons used in the correlation, then describe the various sections and discuss their correlations. Finally the conclusions reached will be summarized.

Critical Horizons

A study of the Silurian of Maryland and adjacent areas has disclosed in the lower part of the McKenzie, the Rochester, and the upper part of the Rose Hill a clearly recognizable and diagnostic series of lithological and faunal units that may be followed over large areas. It comprises the following members:

McKenzie formation	Zone of *Orthoceras mackenzicum*.
	Zone with *Camarotœchia andrewsi* and numerous ostracoda of the genera Klœdenella, Euklœdenella, etcetera.

[11] Bull. Geol. Soc. Amer., vol. 35, 1923, pp. 104-105.

[12] The Rochester was included in the typical Clinton section by Vanuxem. The pre-Rochester portion of the Clinton was named the Rose Hill by the senior author in 1923 for reasons that are set forth in the Silurian monograph of the Md. Geol. Surv., 1923, pp. 27-28.

Rochester shale	Zone of profuse *Whitfieldella marylandica* with the ostracoda *Drepanellina ventralis* (a) and *Beyrichia veronica* (a). Zone of Dalmanites limulurus, *Calymmene niagarensis*, and profuse Rochester fauna with the ostracoda *Drepanellina clarki* (a) and *Parachmina spinosa* (aa) with *Homalonotus delphinocephalus*.
Keefer sandstone	
Rose Hill formation	Zone of *Liocalymmene clintoni*, *Calospira sulcata*, *Chonetes novascoticus* with the ostracod *Mastigobolbina typus* (a). Zone of *Liocalymmene clintoni*, etcetera, with the ostracod *Bonnemaia rudis* (a).

FIGURE 1.—*Map showing Locations of Sections*

1. Cumberland, Maryland, 2. West of Hancock, Maryland, 3. West of Fairview Mountain, Maryland, 4. Marklesburg, Pennsylvania, 5. Saltillo, Pennsylvania, 6. Honey Grove, Pennsylvania, 7. Loysville, Pennsylvania, 8. North of Harrisburg, Pennsylvania, 9. Swatara Gap, Pennsylvania, 10. Schuylkill Gap, Pennsylvania, 11. Rausch, Pennsylvania, 12. Lehigh Gap, Pennsylvania, 13. Smiths Gap, Pennsylvania, 14. Wind Gap, Pennsylvania, 15. Road to Fox Gap, Pennsylvania, 16. Delaware Water Gap, Pennsylvania, 17. Poxono Island, Pennsylvania, 18. Nearpass Quarry, New Jersey, 19. Graham Station, New York, 20. Otisville, N. Y., 21. High Falls, N. Y., 22. Danville, Pennsylvania.

The McKenzie consists of interbedded shale and dark, dense limestone, the lower beds of which contain, locally, limestone conglomerates. The Rochester shale contains blue crystalline lenticular limestone. The Keefer sandstone is thin and locally calcareous in the west; eastward it grows massive and thick. Iron ores locally replace limestones above or below the Keefer sandstone. The Rose Hill formation consists largely of shale, but sandstones occur in it locally, at various horizons, increasing in volume eastward. The faunas diminish toward the east in these horizons, but the lithology remains valuable for correlation.

The series of zones affords valuable criteria for correlation. We shall follow them eastward from Maryland. Where the faunas cease, reliance must be placed upon stratigraphic and lithologic relations. The accompanying map shows the locations of the sections. They are numbered as in the plate of sections.

Description and Correlation of Sections [13]

Sections in Pennsylvania west of Susquehanna River

Loysville.—Loysville is in Perry County, 25 miles west of Harrisburg, Pennsylvania. Sections affording almost uninterrupted exposures of the beds from the upper part of the Rose Hill formation to the lower third of the Tonoloway limestone were measured in this region; the middle part of the Tonoloway was not seen, but the Upper Tonoloway is well exposed. In combination with the section at Honey Grove, 11 miles west of Loysville, the sections in this vicinity permit of almost complete measurements of the Silurian of this region from the top of the Tuscarora to the base of the Helderberg formation. They also afford excellent opportunity for collecting fossils from the beds named.

Sections are exposed at three localities: (1) beginning at the covered bridge, 1½ miles west of Loysville at the fork of the road leading from Loysville to Center, Pennsylvania, and extending along the roads leading (a) to the north and (b) to the west; (2) at Waggoner's Mill, 1 mile west of Loysville; (3) on the road leading south from Center village, 4 miles west of Loysville.

[13] Only the general features of the various sections will be given here. We hope later to publish elsewhere more detailed sections. All the measurements are in feet.

Sections 1½ miles west of Loysville, Pennsylvania

	Thickness in feet Beds	Total
Wills Creek formation:		
Concealed. Soil light colored with bands of red color. Unit of great thickness.....		
Bloomsburg red beds:[14]		
Red sandstone and shale and red soil. Some green beds especially in lower part.....	500	500
Total thickness of Bloomsburg.....		500
McKenzie formation:		
The upper beds of the McKenzie formation are finely exposed along the state road leading to the west, 1½ miles west of Loysville. This is an admirable locality for collecting fossils.		
Interbedded green and blue sandstone and sandy shale. Some red mottling at top of unit.....	8.8	109.8
Olive-gray shale and thin bands of dark-blue limestone. The upper shale beds split obliquely to bedding. Containing *Camarotœchia andrewsi,* (c); *Lingula oblongata* (a) 3.5 feet above base; *Liopteria* n. sp. (a) 5 feet above base; *Modiolopsis* n. sp. (aa) 8.5 and 11.5 feet above base. *Orthoceras mackenzicum* (a) 8.5 and 19.5 feet above base. Many ostracods in lower 29 feet of this unit.....	42	101

Section seen in bluff east of dam at Waggoner's Mill, 1 mile west of Loysville

	Thickness in feet Beds	Total
Concealed on hillside. Near base were exposed, in a trench, fissile and gray shale and thin bands of dense dark-blue limestone. At base is a bed of limestone conglomerate 3 inches thick. Some limestone beds abound in ostracods.[15] In loose fragments of limestone were collected *Dizygopleura swartzi, Klædenella scapha*.....	59	59
Total thickness of the McKenzie formation.....		109.8

[14] The Bloomsburg was measured along and in fields west of the road leading north from the state highway at covered bridge. The top of the Bloomsburg is seen in fields west of road, 50 feet north of the south side of the right-of-way of railroad. The lower part of the Bloomsburg is concealed on the road to the north, but is well exposed on the road leading to the west. The thickness of the Bloomsburg measured was 499 feet.

[15] These beds are concealed on the road 1½ miles west of Loysville. Their thickness was determined by measuring the interval from the top of the Keefer sandstone to the base of the Bloomsburg, along the state road east of the covered bridge, east of Waggoner's Mill. The base of the McKenzie is placed at the base of a limestone conglomerate, in harmony with former usage. We expect later to publish an article upon the proper position of the base of the McKenzie.

	Thickness in feet Beds	Total
Rochester formation:		
The Keefer sandstone and the overlying Rochester shale are well exposed in the bluff east of the mill pond, east of Waggoner's Mill. The shale beds are best seen north of the dam, the Keefer sandstone above the spillway below the dam.		
Fissile gray shale with a thin bed of blue limestone in middle. In shale, at top, *Whitfieldella marylandica* (a). This unit was exposed in a trench	8	70
Fissile gray shale containing at top *Liopteria subplana* small var. (a), *Euklædenella longula*	2.5	62
Interbedded blue crystalline limestone and fissile gray shale. Some beds of limestone abound in *Whitfieldella marylandica* and contain in addition *Pholidops squamiformis, Beyrichia veronica* (aa), *Drepanellina ventralis* (a), *Dizygopleura pricei, D. proutyi* (c), *Euklædenella sulcifrons* (c), *Klædenella scapha* (a). This is the *Whitfieldella marylandica-Drepanellina ventralis* zone	3	59.5
Interbedded blue crystalline limestone and fissile gray shale. Shale weathering greenish. This unit bears *Favosites* sp., *Camarotœchia neglecta* (a), *Dalmanella elegantula* (aa), *Leptæna rhomboidalis, Reticularia bicostata* (c), *Orthis tenuidans* (?), *Pholidops squamiformis, Strophcodonta corrugata* (c), *Whitfieldella marylandica* (r), *Tentaculites* sp., *Dalmanites limulurus* (a), *Encrinurus ornatus* (a), *Homalonotus delphinocephalus, Drepanellina clarki* (a)	7	56.5
Keefer sandstone member:		
Thin-bedded gray sandstone and gray calcareous shale. Richly fossiliferous zones near base and at top contain *Atrypa reticularis, Camarotœchia neglecta, Dalmanella elegantula, Leptæna rhomboidalis, Orthis tenuidans, Pholidops squamiformis* (a), *Reticularia bicostata, Rhipidomella hybrida, Schuchertella tenuis, S.* n. sp., *Strophcodonta corrugata* (a), *S. corrugata* var. *pleuristriata, S. (Brachyprion) profunda* a, *Uncinulus brevirostris, U. obtusiplicatus* (?) (c), *Ctenodonta* aff. *curta, C. circularis,* cf. *Grammysia kirklandi, Liopteria* sp., *Pyrenomœus* cf. *cuneus, Pterinea emacerata, Bucanella trilobata, Platyostoma niagarense, P. plebeum, Cornulites concavus, Dalmanites limulurus, Homalonotus delphinocephalus, Drepanellina clarki, Paræchmina spinosa,* and other ostracoda	17.5	49.5
Massive gray sandstone containing *Homalonotus delphinocephalus* (r)	12	32

	Thickness in feet Beds	Total
Argillaceous gray sandstone and some interbedded gray shale.[16]	20	20
Total thickness of Rochester formation		70
Rose Hill formation:		
Olive-green shales exposed by road south of mill, containing *Bonnemaia crassa*, n. var.	10	118.5

Sections seen along county road leading south from Center, 3/4 mile south of the village[17]

Concealed above. Yellow to olive shale and some bands of sandstone below. Some of the lower shale beds are slightly pink. In rusty calcareous sandstone, 17 feet above the base of this unit, occur *Chonetes novascoticus* (a), *Cœlospira hemispherica* (a). At the base of this unit occur *Liocalymmene clintoni* (a) and *Bonnemaia rudis* (a)	72.5	108.5
Massive red-brown iron sandstone with interbedded shale which is similar to that described above. *Bonnemaia rudis* (a) at top. The Center Iron Sandstone	36	36
Total thickness of Rose Hill formation described		118.5

Correlation.—The correlation of the beds with the corresponding strata of Maryland, indicated above, is fully established by their rich and varied faunas. Their relationship is shown by the following table which gives the sequence at Loysville and in Maryland.

Bloomsburg red beds.

McKenzie formation:

Camarotachia andrewsi fauna with *Orthoceras mackenzicum* zone 80 to 100 feet above base.

Rochester shale:

Whitfieldella marylandica-Drepanellina ventralis zone above *Dalmanites limulurus-Drepanellina clarki* zone below.

Keefer sandstone:

Rochester fauna.

Uper part of Rose Hill shale:

Zone rich in *Liocalymmene clintoni-Chonetes novascoticus* Ostracoda of *Mastigobolbina typus* zone above Ostracoda of *Bonnemaia rudis* zone below.

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[16] The base of this bed is 6 feet above water level at the spillway, where the underlying beds are concealed. Its base is the approximate base of the Keefer sandstone.

[17] The upper 31.5 feet of the Keefer sandstone, including the middle massive beds, are well exposed here. The lower more argillaceous sandstone, of which 20 feet are seen at Waggoner's Mill, is concealed.

The similarity of faunal zones, the richness of the faunas, the identity of lithology, and the sequence of formations clearly establish the correlations shown.

Center iron sandstone.—It is proposed to call the massive iron sandstone, seen in the section at Center, the Center iron sandstone. It is widely extended, being found at approximately this horizon at many places.

Honey Grove, Marklesburg and Saltillo.—Sections at Honey Grove and Marklesburg are described by Ulrich in the volume on the Silurian of Maryland,[18] and that at Saltillo is described by Ashburner.[19] They are shown on the accompanying plate of sections. They connect the sections at Loysville more closely with that at Cumberland, Maryland. The sections by Ulrich show the ostracod zones as interpreted by him; the section at Saltillo shows a step in the transition of the Upper McKenzie into the Bloomsburg red beds. They harmonize fully with the interpretation given above.

Danville.—Danville, on the North Branch of the Susquehanna River, is the most easterly locality at which richly fossiliferous strata of this age were observed. An excellent section, extending from the Tuscarora to the lower Bloomsburg, is exposed along the State highway 2 miles west of Danville. The section of the Upper Bloomsburg and Wills Creek, described by I. C. White from Big Fishing Creek,[20] is also used in the plate of sections. Danville affords excellent exposures for collecting fossils in the Upper Rose Hill, Rochester and McKenzie.

Section on State highway, 2 miles west of Danville, Pennsylvania [21]

	Horizontal Total	Thickness Beds	Thickness Total
Bloomsburg red beds:			
Concealed on west	120	.....	.....
Red sandstone and shale. Some thin green beds. *Lingula* sp. (a), 90 feet below top (at 403 of traverse)	1,189	404	404
McKenzie formation:			
Greenish shale, some thin beds of dense dark-blue fossiliferous limestone	1,223	17.6	156.5

[18] E. O. Ulrich: Md. Geol. Surv., Silurian, 1923, pp. 353-354; 357-358.

[19] C. A. Ashburner: Second geological survey of Pennsylvania, vol. F, 1878, p. 248.

[20] I. C. White: Second geological survey of Pennsylvania, vol. G7, 1883, pp. 220-221.

[21] The horizontal traverse begins at center of bridge over small stream 3 miles west of Danville (State highway station 569+60) and extends eastward 7,540 feet along the highway.

	Horizontal Total	Thickness Beds	Thickness Total
Red shale	....	2.4	138.9
Interbedded gray calcareous shale and dark-blue limestone. Limestone containing *Camarotœchia andrewsi* (aa), *Lingula* sp. (aa), *Liopteria* sp., and *Reticularia bicostata* (a) 44 feet above base	1,440	93.5	136.5
Gray calcareous shale above; 1-foot limestone conglomerate at base	1,540	43	43
Total thickness McKenzie formation			156.5
Rochester formation:			
Interbedded gray, calcareous shale and dark-blue lenticular crystalline limestone. The limestone contains a profusion of *Whitfieldella marylandica* and also bears *Encrinurus ornatus. Drepanellina ventralis* (a) and *Eukladenella sulcifrons* occur 2 feet below top of bed	....	22	99.5
Interbedded gray calcareous shale and dark-blue crystalline limestone containing *Atrypa reticularis* (a), *Camarotœchia neglecta* (a), *Dalmanella elegantula* (a), *Leptœna rhomboidalis, Pholidops squamiformis, Rhipidomella hybrida, Schuchertella tenuis* (?), *Stropheodonta corrugata* (a), *Liopteria* sp., *Pterinea emaccrata, Pterinea* sp., *Dalmanites limulurus* (a), *Homalonotus delphinocephalus, Drepanellina clarki* (a), and other ostracoda. *Uncinulus stricklandi* occurs near the base of the unit	....	22	67.5
Keefer sandstone member:			
Hard gray calcareous sandstone with some interbedded shale and limestone and a thick gray shale in middle. Containing *Camarotœchia neglecta, Dalmanella elegantula* and crinoid rings	1,756	45.5	45.5
Total thickness Rochester formation			99.5
Rose Hill formation:			
Interbedded greenish shale and very fossiliferous greenish-blue limestone, containing *Atrypa reticularis* (aa), *Cœlospira sulcata* (aa), *Chonetes novascoticus* (a), *Dalmanella elegantula* (a), *Leptœna rhomboidalis* (c), *Spirifer eudora* (?), *Stropheodonta corrugata* (?), *Tentaculites minutus, Liocalymmene*			

	Horizontal Total	Thickness Beds	Thickness Total
clintoni (c), *Bonnemaia oblonga* (c), *Beyrichia lakemontensis* (c), *Dizogopleura loculata* (c), *Mastigobolbina typus* (c), *M. triplicata* (a), *M. bifida* (c), *Paraechmina crassa* (?), *Plethobolbina typicalis*, *Zygosella vallata* (c), and *Z. vallata* var. *nodifera* (c). 17 feet below the top occurs *Dalmanites limulurus*	1,875	50	867
Concealed. Slope covered with fragments of fissile olive-green shale.[22]	5,015	817	817
Total thickness of Rose Hill formation			867
Traverse parallel to strike to center small cement bridge	7,540		
Tuscarora sandstone:			
Sandstone, massive greenish-gray below; brown, red, or gray and somewhat shaly above. Exposure east of stream		120	120
Concealed.			
Total thickness of Tuscarora sandstone exposed			120

Correlation.—That the greenish-blue limestone and shale described above is of Upper Rose Hill age is shown by the presence in it of *Mastigobolbina typus,* the diagnostic ostracod species of the *M. typus* zone of the Upper Rose Hill, as well as by the presence of *Liocalymmene clintoni, Chonetes novascoticus,* and *Tentaculites minutus,* also characteristic of the same zone. It is overlain by the Keefer sandstone. Above the latter is the Rochester shale containing the *Dalmanites limulurus-Drepanellina clarki* fauna and many associated Rochester species. At the base of the shale is the *Uncinulus stricklandi* zone found at many localities at this horizon.

At the top of the Rochester is the *Drepanellina ventralis* zone, marked by the same profusion of *Whitfieldella marylandica,* associated with *Drepanellina ventralis,* found in Maryland and at Loysville at the same position. These beds are succeeded in turn by the McKenzie, with its diagnostic *Camarotœchia andrewsi* fauna, and the Bloomsburg red beds. The Wills Creek and Tonoloway overlie the latter. The correlation of these beds with corresponding strata in the sections at Loysville and in Maryland is manifest.

North of Harrisburg.—The section described below was measured in the gorge cut by the Susquehanna River through Blue Mountain, 4 miles

[22] I. C. White records the occurrence of iron sandstone 30 feet thick about 100 feet below the top of this unit (op. cit., p. 340). We did not see it.

north of Harrisburg, Pennsylvania. The lower part of the section is seen in the Pennsylvania Railroad cut west of the river. The middle part appears as ledges and riffles in the bed of the river, and we measured it from a boat at a low stage of the river. The upper beds, although largely concealed, are partly exposed along the railroad west of the river. The top of the section is seen in a small quarry north of the west end of the railroad bridge over the Susquehanna.

The formations between the Bloomsburg and the Hamilton sandstones are cut out by a fault or unconformity.

Section exposed along railroad tracks west of Susquehanna River

	Horizontal [23]	Thickness Beds	Thickness Total
Hamilton sandstone:			
Massive gray sandstone and some shale	.....	.....	.....
Bloomsburg red beds:			
Concealed.[24]	2,921	146	507
Concealed, red shale soil in trenches at top	2,761	48	361
Red sandstone and shale at top. Concealed below	2,708	213	313
Concealed. Some red shale soil. Dwelling house at 2,471 of traverse	2,471	100	100
Thickness of Bloomsburg formation described			507
Concealed, embracing beds extending from lower Bloomsburg to Rochester shale inclusive	.....	1,007	1,007

Section exposed in bed of Susquehanna River

Rochester formation.			
Keefer sandstone member:			
Massive gray sandstone. Its top, projected, intersects highway on west side of river, 30 feet north of the Cumberland-Perry County line. (The latter is at station 347+23 of the State highway survey.)	1,213	21	763
Rose Hill formation:			
Concealed	1,188	79	742
Massive iron sandstone	1,093	17	663
Concealed. Two beds of gray sandstone in lower third	1,078	116	646

[23] The traverse begins at the base of the Tuscarora sandstone in the railroad cut and extends northward along the railroad tracks.

[24] Probably Bloomsburg as indicated by the topography.

	Horizontal	Thickness	
		Beds	Total
Massive sandstone. Middle 12 feet concealed...	943	46	530
Concealed	888	60	484
Massive iron sandstone.....	818	41	424
Concealed	763	143	383
Massive iron sandstone—concealed in part....	603	64	240
Concealed	528	40	176
Massive gray sandstone.....	483	16	136
Concealed	465	77	120
Section seen along Pennsylvania Railroad, west of river			
Medium-bedded gray sandstone seen high above railroad cut [25]	373	9	43
Concealed	363	34	34
Total thickness of Rose Hill formation.....			742
Tuscarora sandstone:			
Medium-bedded gray sandstone seen high in cut	324	107	277
Massive red sandstone.....	199	30	170
Massive gray sandstone, lower 7.5 feet conglomeratic	164	86.5	140
Very massive gray sandstone forming a great ledge in river.....	62	53.5	53.5
Total thickness of Tuscarora sandstone.....			277
Juniata formation:			
Interbedded sandstones and massive conglomeratic sandstones, red, with subordinate amounts of gray. Pebbles up to 2 inches long. The top of this unit is at station 366+20 of the State highway survey.....		39.5	75
Red sandstone and shale.....		35.5	35.5
Total thickness of Juniata formation.....			75
Martinsburg shale:			
Concealed. Fragments of gray shale in bank. Extensive exposures of Martinsburg shale to south.....		.....	.....

Correlation.—No fossiliferous beds were observed in the above-described section, the shale beds in which fossils might be expected being

[25] This may possibly be Tuscarora. The section is concealed on railroad north of this.

all concealed, and it is therefore impossible to correlate it by faunas. It is distant, however, but 25 miles from Loysville and presents numerous lithological features that may be compared with those at Loysville, as follows:

Loysville, Pennsylvania	Harrisburg, Pennsylvania
Bloomsburg red beds and shale of great thickness.	Bloomsburg red beds and concealed (shale) of great thickness.
Keefer sandstone 50 feet, about 30 feet more massive.	Keefer sandstone, massive ledge, 21 feet exposed in river.
Upper part of Rose Hill shale and concealed, 82 feet.	Concealed upper part of Rose Hill shale, 79 feet.
Center iron sandstone, 36 feet.	Center iron sandstone in ledge, 17 feet.
Interval to base of Rose Rill, about 700 feet.	Interval to base of Rose Hill, 646 feet.
Tuscarora sandstone.	Tuscarora sandstone.

The above comparison shows the relationship of the beds to be so close as to permit little doubt of the correlation suggested. The chief difference is in the increasingly arenaceous character of the beds in approaching the old shoreline toward the southeast, a feature in harmony with the general relations of the region. A conspicuous feature of the section is the great development of iron sandstones in the middle portion of the Rose Hill, which becomes still more marked farther east.

SECTIONS IN PENNSYLVANIA EAST OF SUSQUEHANNA RIVER

General statement.—East of the Susquehanna the Great Valley is bounded on the northwest by a bold mountain ridge, variously known as Blue Mountain toward the west, as Kittatinny Mountain at the Delaware River, and as Shawangunk Mountain in New Jersey and New York. This mountain is pierced by the gorges of four streams—Swatara Creek, and the Schuylkill, Lehigh, and Delaware rivers—between Harrisburg, Pennsylvania, and Otisville, New York. These gorges afford the best, and indeed the only well-defined sections within the region named.

The rocks become increasingly arenaceous and barren east of the Susquehanna River, only one locality—Swatara Gap—yielding marine fossils. It is therefore not possible to use marine fossils for correlation east of the latter point. It is possible, however, to employ stratigraphic relations and lithological features in neighboring sections, and by means of these, adequate correlations may be obtained.

Between Susquehanna and Lehigh Rivers.—Swatara Gap. Swatara Gap [26] is situated 23 miles northeast of the section described north of Harrisburg and 11 miles northwest of Lebanon, Pennsylvania. At the southern end of the gap is Inwood Station, on the Philadelphia & Reading Railway.

The contact of the Martinsburg and Tuscarora is well shown at the north side of a small quarry in the Martinsburg, on the west side of the creek nearly opposite the railroad station. The section described is seen along the county road east of the stream.

Section east of Swatara Creek

The horizontal traverse begins 375 feet north of the east end of the iron bridge and extends northward along the county road.

	Horizontal Total	Thickness Beds	Thickness Total
Marcellus formation:			
Black carbonaceous shale. *Liorhynchus limitare* (aa).....	....	.....	.....
Onondaga limestone:			
Concealed above. Impure, somewhat argillaceous limestone below containing *Phacops cristata, Atrypa reticularis, Leptæna rhomboidalis, Pentagonia unisulcata, Strophеodonta inequiradiata* (?), etcetera.....	3,560	20	20
Total thickness of Onondaga limestone.....			20
Inwood sandstone:			
Greenish-gray, argillaceous, somewhat arkosic sandstone. Concealed above. Age unknown, probably Cayugan.....	3,540	49	49
Bloomsburg red beds:			
Red sandstone and shale with some green bands. Center of dwelling 2,974 of traverse..	3,490	1,126	1,586
Brown calcareous shale and interbedded red and green shale. *Leperditia* sp. (a), 8 feet above base.....	2,344	26	460
Red sandstone and shale, some green shale and hard greenish-gray sandstone especially in lower part. *Arthrophycus* cf. *alleghaniensis*			

[26] Dr. Gilbert Van Ingen made a critical study of this section and collected in it numerous Eurypterids that were identified by Clark and Ruedemann in their memoir on the Eurypterids of New York (N. Y. State Mus., Mem. 14, 1912, pp. 418-419). Dr. Van Ingen unfortunately never published the results of his studies. We were permitted through the courtesy of Dr. B. F. Howell of Princeton to examine Dr. Van Ingen's notes and locate the beds in which he collected the specimens identified by Clark and Ruedemann. Full credit is given Dr. Van Ingen and the significance of the Eurypterids is more fully discussed in an article by us in the Amer. Jour. Sci., vol. 20, 1930, pp. 467-475.

	Horizontal Total	Thickness Beds	Thickness Total
in place 16 feet above base (1,920 feet of traverse). Top of deep prospect at 2,004.4 of traverse	2,317	401	434
Greenish argillaceous sandstone 4.5 feet thick, at top, concealed below	1,907.5	31	33
Red arenaceous shale	1,875	2	2
Total thickness of Bloomsburg red beds			1,586
Rochester or McKenzie formation:[27]			
Greenish-gray sandstone 8 feet thick at top, concealed below	1,873	20	1,411
Massive gray sandstone middle part concealed. Van Ingen reports *Eurypterus maria* in this interval	1,853	91	1,391
Total thickness			110
Rochester formation:			
Concealed above. Gray shale below	1,762	15	1,300
Calcareous sandstone above, gray shale below. The sandstone bears *Drepanellina ventralis* (a), *Beyrichia veronica* (aa), *Dizygopleura pricei* (c), *Parœchmina postica*, *Whitfieldella marylandica* (c), *Camarotœchia* sp., *Liopteria subplana* small var. (a). The shale contains *Whitfieldella marylandica*, *Goniophora speciosa*, *Pyrenomœus* n. sp. (aa). The *Whitfieldella marylandica-Drepanellina ventralis* zone	1,746	2	1,285
Interbedded shale and argillaceous gray sandstone, much concealed	1,744	96	1,283
Keefer sandstone member:			
Gray to bluish-gray sandstone and some interbedded shale, partially concealed by drift from dump. The sandstone contains *Rhipidomella hybrida* (c), *Camarotœchia neglecta* (a), *Dalmanella elegantula*, cf. *Homœospira* sp., *Posidomya rhomboidea*, *Pterinea emacerata* (c)	1,643	26	1,187
Total thickness of known Rochester formation			124
Rose Hill formation:			
Argillaceous sandstone and arenaceous shale, containing, near base, some oolitic hematite			

[27] These beds occupy the position of the lower McKenzie beds farther west. The absence of all marine fossils makes it impossible to determine their age with confidence.

	Horizontal Total	Thickness Beds	Thickness Total
with white quartz grains and some ferruginous bands above it. At the base of this unit, on north wall of open cut occur *Atrypa reticularis, Camarotœchia neglecta* (a), *Dalmanella elegantula, Homœospira* n. sp., aff. *H. evax* (a) cf. *Orthis tenuidans, Whitfieldella intermedia* (c), *Modiolopsis subalatus* (c), *Pterinea* n. sp., aff. *P. finstonensis* but finer plications, anterior wing constricted, *Orthoceras* sp., *Cornulites* n. sp., cf. *Drepanellina* sp., indeterminate bryozoa	1,615	2	1,161
Interbedded arenaceous shale and thin-bedded gray argillaceous sandstone carrying iron sandstone 7 feet thick at top and some thin ferruginous bands in lower 18 inches. Upper part seen in open cut	1,613	36	1,159
Massive gray and iron sandstones and some shale. Gray sandstones 4 to 24 feet and 28 to 45 feet above base	1,575	53	1,123
Concealed above, thin-bedded gray argillaceous sandstone 9 feet thick at base.[28]	1,520	18	1,070
Fissile shale weathering pink, containing *Zygosella* sp.	1,500	17.5	1,052
Greenish sandstone, argillaceous above, massive below	1,481	56.5	1,034.5
Sandstone and shale, red above, gray below. Small prospect in this and next unit	1,414	17	978
Very massive iron sandstone, its lower 35 feet much concealed. Small prospect 1,385 to 1,391 of traverse. Drain at 1,344. The Swatara iron sandstone	1,405	120	961
Concealed above. Iron sandstone, 4 feet thick, exposed in washway at bottom. *Camarotœchia neglecta*, loose, at 1,195 of traverse	1,255	66	841
Concealed. Washway at 1,050 of traverse. Road ascends hill to north at 650 of traverse. Several prospect pits in lower beds	1,173	445	775
Total thickness of Rose Hill formation			831
Tuscarora sandstone: Massive gray sandstone, some beds concealed along road but exposed on slope high above			

[28] Van Ingen reports in this sandstone (Clarke and Ruedemann, op. cit., pp. 418-419) *Eurypterus maria, Hughmilleria shawangunk, Pterygotus globiceps, Stylonurus* cf. *myops. Erettopterus* sp.

	Horizontal Total	Thickness Beds	Thickness Total
road. *Arthrophycus alleghaniensis* on loose slabs.[29]		290	330
Massive gray conglomeratic sandstone, pebbles up to several inches in diameter, exposed above level of road. This bed is clearly seen north of quarry along state road road west of creek		40	40
Total thickness of Tuscarora sandstone			330
Martinsburg shale:			
Dark-gray clay shale exposed in small quarry west of creek, containing *Calymmene granulosa, Cryptolithus recurvus, Isotelus stegops, Triarthus becki, Plectambonites rugosus* (a), etcetera		.....	.....

Correlation.—The relation of this section to that north of Harrisburg is evident. The Bloomsburg is present at both places. The Keefer sandstone appears to be represented by the sandstone containing *Rhipidomella hybrida,* et cetera, 1,161 to 1,187 feet above the base of the section.

The iron sandstone in the upper 91 feet of the Rose Hill appears to represent the Center iron sandstone, whose base is 96 feet beneath the Keefer sandstone at Harrisburg, although higher iron sandstone beds are also represented here. The very massive iron sandstone, here named the Swatara iron sandstone, 511 to 631 feet above the base of the Rose Hill (841 to 961 feet above the base of the section), corresponds in position to the massive iron sandstone 381 to 530 feet above the base of the Rose Hill at Harrisburg. The Tuscarora sandstones occur similarly in both sections.

The chief difference is the increasingly arenaceous and barren character of the beds encountered in going eastward.[30] The age of the massive gray sandstones beneath the Bloomsburg is unknown, owing to the absence of marine faunas. It is probably Cayugan. It is here termed the Inwood sandstone.

[29] Van Ingen reports finding loose in the talus of these beds, west of creek, *Eurypterus maria, Dolichopterus* cf. *otisius, Hughmilleria shawangunk, Pterygotus* cf. *globiceps, Stylonurus, myops,* associated with *Arthrophycus alleghaniensis* (Clarke and Ruedemann, op. cit., p. 419).

[30] When this paper was first presented only a meager fauna was known, consisting chiefly of new and not very diagnostic species. Since that time a number of additional species have been discovered, including diagnostic ostracoda. These faunas are considered more fully elsewhere. (See Amer. Jour. Sci., vol. 20, 1930, pp. 467-475). They fully verify the correlations made earlier by us by means of lithological and stratigraphic criteria.

Schuylkill Gap. The Schuylkill River flows through Blue Mountain in a deep gorge 28 miles northeast of Swatara Gap. An excellent section is exposed along the State highway passing through the gap and leading from Reading to Pottsville, Pennsylvania.

The base of the Tuscarora sandstone is seen at station 2737+10 of the State highway survey, 2,500 feet southeast of the Schuylkill-Berks County line. South of the latter point the Martinsburg shale is exposed for a great distance. The contact of the Martinsburg shale and the Tuscarora sandstone is well shown along the Pennsylvania Railroad, west of the Schuylkill River. The upper beds of the Clinton are described from a section exposed on the north limb of a small anticline one mile farther north.

The traverse begins at the base of the Tuscarora and extends along the highway to the center of a syncline in the village of Port Clinton, 1,838 feet north of the south boundary of the corporation. The measurements are given in terms of the State highway survey stations.

	Horizontal Total	Thickness Beds	Thickness Total
Bloomsburg red beds:			
Axis of small syncline, seen in village	262700	.....	.....
Red sandstone and shale, some green bands. The base of the unit is exposed on road leading west of river	262700	1,200	1,800
Concealed to base of formation.[31] Spring at 261780. South boundary of corporation at 260862	262100	600	600
Total thickness of Bloomsburg formation described			1,800
Clinton formation:			
Concealed[32]	260878	78	1,415
Argillaceous sandstone and shale, partially concealed. (The lower part of this unit is mottled with red in the section 1 mile north of village)	260795	56	1,337
Hard, massive greenish-gray laminated sandstone with shale partings. Lower 13 feet thinner-bedded	260735	193	1,281

[31] This unit, consisting of red sandstone and shale, is exposed in the anticline 1 mile farther north. The top of the Bloomsburg is not exposed in the syncline at this place. A section measured along the county road 1 mile north of Rauschs, 7 miles northeast of Port Clinton, gave a thickness of 1,815 feet to the Bloomsburg at that place.

[32] These beds are exposed beneath the Bloomsburg along the highway in the anticline 1 mile north of village, where they consist of gray shale and argillaceous sandstone, partially concealed.

	Horizontal Total	Thickness Beds	Thickness Total
Red to red-brown or red-mottled sandstone and shale, interbedded with greenish-gray argillaceous sandstone and shale	260551	34	1,088
Greenish-gray argillaceous sandstone and shale, upper foot red-mottled	260516	45	1,054
Massive brown or red-mottled sandstones and shales and some greenish-gray beds	260469.5	50	1,009
Greenish-gray shale and sandstone, a bed of iron sandstone 2 feet thick in middle	260423	57	959
Red-brown or red-mottled sandstone interbedded with greenish-gray sandstone and shale	260358	117	902
Greenish-gray argillaceous sandstones and shale, a thrust fault in lower part. Its base may be approximately 630 feet above base of section	260209	155	785
Thrust fault:			
Concealed	260030	98	1,417
Arenaceous shale and argillaceous sandstone partially concealed	259930	73	1,319
Massive greenish-gray sandstone, in beds up to 18 inches thick, and some shale	259856	145	1,246
Thin-bedded greenish-gray shale	259709	19	1,101
Greenish-gray argillaceous sandstones and shale interbedded with some red-brown iron sandstones and shales. A few beds mottled with red	259690	386	1,082
Arenaceous shale. The base of this unit is at 259275 of traverse	259283	9	696
The beds from 259275 to 255400 are repeated by curving of road and hence are omitted here.[33]	.....	.....	.....
Gray sandstone, heavy-bedded below, upper 9 feet argillaceous. Some shale	255400	149	687
Concealed	255000	95	538
Total thickness of Clinton formation			972

[33] The lowest horizon exposed here is at station 258740 which is probably about 275 feet above the base of the Tuscarora. A traverse from station 258532 bears south 8 degrees east, 369 feet to the base of the Tuscarora by river. Road is farthest south at 258500. County line is at 256212.

	Horizontal Total	Thickness Beds	Thickness Total
Tuscarora sandstone:			
Heavy-bedded, somewhat argillaceous gray sandstone	254800	320	443
Massive hard gray sandstone with numerous *Arthrophycus alleghaniensis*. The lower 5 feet are conglomeratic west of river	253985	123	123
Total thickness of the Tuscarora sandstone			443
Dark-gray clay shale and greenish sandstones. The upper 50 feet concealed here but well exposed along railroad west of river	253710	.....	.....

Correlation.—The interpretaion of this section is difficult; the section is complicated by thrust faults which obscure its relationships. Carefully checked measurements appear to give a thickness of 2,201 feet from the base of the Tuscarora to the base of the Bloomsburg. The corresponding beds at Swatara Gap on the west are 1,411 feet thick, and at Lehigh Gap on the east are 1,550 feet thick. At both of these places good measurements were obtained and the sections are in close agreement in details. From these facts it seems probable that the thrust faults have duplicated the beds of this section, causing the great apparent thickness. Basing the interpretation on this conjecture the section has been described as given above. This interpretation brings the beds into good agreement with those of neighboring sections.

Although the above results are uncertain, owing to the complications mentioned, it is manifest that the Tuscarora, Clinton and Bloomsburg are present here and that their general lithological features are unchanged. Moreover, it seems possible that the massive sandstone, 1,088 to 1,281 feet above the base of the section, is the Keefer sandstone.

Lehigh Gap.—The Lehigh River flows in a deep gorge through Blue Mountain 26½ miles northwest of Schuylkill Gap, making an excellent exposure in the gap south of Palmerton.

The sections described are at four localities in the gap: (1) Along the State highway leading from Slatington to Palmerton; (2) along the Lehigh & New England Railroad east of the river; (3) along the county road leading to the east from the State highway, north of Aquanchicola Creek; (4) along the Lehigh Valley Railroad, west of the river and opposite Lehigh Gap station.

Section along State highway south of Palmerton Borough [34]

	Horizontal Total	Thickness Beds	Thickness Total
Bloomsburg red beds:			
Concealed. Soil of mingled red shale and river boulders	....	.....	.....
Concealed to south boundary of borough of Palmerton. Red soil of Bloomsburg type	100000	246	1,168
Red sandstone and shale, occasional green bands	99700	900	922
Concealed on highway. Red sandstone and shale exposed on road along Aquanchicola Creek and on Lehigh Valley Railroad west of river	98600	22	22
Thickness of Bloomsburg red beds described [35]			1,168
Clinton formation:			
Concealed on highway. Variegated green and red beds form this unit on the Lehigh Valley Railroad west of river.[36]	....	45	1,550
Concealed along State highway. Thin-bedded greenish-gray sandstone, its top heavier-bedded, is exposed on Lehigh Valley Railroad west of river. Upper 5 feet is also seen on road along Aquanchicola Creek	....	47	1,505
Thin-bedded gray sandstone and arenaceous shale exposed back of dwelling east of highway	98440	25	1,458
Massive laminated greenish-gray sandstone and some shales, its top thinner-bedded	98405	203	1,433
Olive-green shale and interbedded greenish-gray sandstone. (The north end of Lehigh Gap railroad station is 98000 of traverse)	98100	76	1,230
Red sandstone and shale, 1.5 green shale at top	97970	17	1,154
Green arenaceous shale	....	4	1,137
Concealed along highway across Aquanchicola Creek	....	86	1,133

[34] The traverse along the highway is in terms of the stations of the Pennsylvania State highway survey, marked along the road. Measurements are to the tops of the units.

[35] The full thickness of the Bloomsburg is nowhere shown in this region. A number of deep wells were drilled in Palmerton on approximately a strike line running about 1,200 feet north of the end of this section, measured at right angles to the strike. All were in light-colored materials. Limestone was reported in some of them. It seems not improbable that they are in the basal limey beds, seen at New Ringold a short distance above the top of the Bloomsburg. This would indicate that the Bloomsburg may be about 2,000 feet, more or less, in this region.

[36] The propriety of referring these beds to the Clinton is questionable. Red variegation appears also in the upper gray bed beneath the Bloomsburg elsewhere.

Section continued on Lehigh & New England Railroad east of Lehigh River

	Horizontal Total	Thickness Beds	Thickness Total
The traverse begins at base of Tuscarora a short distance north of the east end of bridge over river and extends north along railroad.	....	.....	.....
Very massive greenish-gray sandstone with some argillaceous sandstone and shale. Concealed to northeast	....	44.9	1,047
Massive brown iron sandstone. A single bed, 5 feet thick	....	20.5	1,002.1
Greenish-gray sandstone above, brown iron sandstone below	....	7.5	981.6
Hard greenish-gray sandstone and a little shale. A bed of brown sandstone in middle	....	95.3	974.1
Greenish-gray sandstone and shale with interbedded iron sandstone and some red shale	....	54.8	878.8
Concealed on railroad thickness of 219 feet	....	.....	.....
Section continued on State highway			
Concealed	....	17.7	824
Greenish-gray shale and sandstone, 3.3 red sandstone and shale in middle. The top of this unit is at south side of dwelling	97252	88.3	806.3
Concealed	97120	48	718
Greenish-gray laminated sandstone, thin- and thick-bedded	97040	23	670
Concealed along highway to 96280	97000	42	647
Section on Lehigh & New England Railroad, east of river			
The traverse begins at base of Tuscarora sandstone, south of the east end of the bridge over river, and extends northward along the railroad	....	.....	.....
Argillaceous greenish-gray sandstone and shale. Sandstone beds up to 2 feet thick	2,182	98	605
Concealed	1,950	50	507
Total thickness of Clinton formation			1,093
Tuscarora sandstone:			
Massive gray conglomeratic sandstone	900	52	457
Concealed in large part. Massive gray conglomeratic sandstone exposed at places	790	165	405
Massive gray sandstone with some thin bands of black shale; many beds of sandstone are			

	Horizontal Total	Thickness Beds	Thickness Total
conglomeratic with pebbles up to several inches in diameter; some black shale pebbles	450	237.5	240
Disintegrated conglomerate, stained yellow..	....	2.5	2.5
Total thickness of Tuscarora formation.....			457
Martinsburg shale:			
Dark-gray shale and gray argillaceous sandstone	....	.....	.....

Correlation.—The sections at Lehigh Gap and at Swatara Gap show marked similarity. The thick and massive sandstone 1,230 to 1,433 feet above the base of the section suggests by its position the thick sandstone zone at Swatara Gap bearing the Rochester fauna in its lower part.

The very massive iron sandstone zone, extending from 878 to 1,002 feet above the base of the section, corresponds so closely to the zone of similar massive iron sandstones between 841 and 961 feet above the base of the section at Swatara Gap as to permit of little doubt of their identity. The lower Clinton beds are shaly in both sections.

The Tuscarora sandstone has increased in thickness from 330 feet at Swatara Gap and 443 feet at Schuylkill Gap to 457 feet at Lehigh Gap, and at the same time has grown increasingly massive and conglomeratic in approaching the old shoreline. The thickness of the Clinton also is somewhat greater. The Shawangunk character of the Tuscarora conglomerate is apparent.

It is evident from the examination of the sections hitherto described that *the Clinton and Tuscarora have been continuously traced eastward across the area, beneath the Bloomsburg, from Maryland to this point.*

Between Lehigh and Delaware Rivers.—Little Gap, Smiths Gap, Power Line of Pennsylvania Light and Power Company, Wind Gap.—A great change in the character of the beds occurs between the Lehigh and Delaware Rivers. So great is this change that it renders uncertain the correlation of the sections by means of their lithology. It seemed desirable, therefore, to trace the beds continuously, if possible, along the mountain between the rivers. The mountain, however, is heavily forested and its slopes are covered by talus, making such work difficult. Four sections were accordingly studied between Lehigh and Delaware Water Gaps, a distance of 29 miles, located respectively at Little Gap, 4 miles east of Lehigh Gap; Smiths Gap, 10 miles east; the power line of the Pennsyl-

vania Light and Power Company, 13½ miles east; and Hahns Outlook at Wind Gap, 17 miles east.[37]

Six lithological horizons can be traced in the mountain throughout this region, namely, three sandstone zones, a thick body of shale above the lowest sandstone, and the Bloomsburg red beds and Martinsburg shale at the top and bottom of the sections respectively.

The Bloomsburg outcrops a short distance below the north crest of the mountain, where its red rocks are conspicuous; through erosion at the major stream gorges, it there lies a little lower.

The upper sandstone zone forms the crest of the north slope of the mountain. It is unchanged at Little Gap; it becomes conglomeratic at Smiths Gap, and increasingly massive and conglomeratic east of this latter point.

The middle sandstone zone forms the crest of the south slope of the mountain, or, where the mountain top is narrow as at Hahns Outlook, the mountain backbone itself. With it is a very massive and characteristic zone of iron sandstones as far east as Smiths Gap. East of the latter point the iron sandstones were not observed, and the gray sandstones become increasingly massive and conglomeratic.

The shale zone lies beneath the crest on the south slope of the mountain. It is conspicuous at Smiths Gap and at the Pennsylvania Light and Power line. East of the latter point it is obscured by talus, but is manifestly present.

The massive gray conglomeratic sandstone zone, the Tuscarora sandstone, forming the lower slope of the south side of the mountain, can be traced above the Martinsburg shale to the Delaware Water Gap.

Thus these sandstone zones may be traced eastward little altered at Little Gap, becoming increasingly massive and conglomeratic farther east, to unite and form the Shawangunk conglomerate at the Delaware Water Gap. The outstanding feature of the region is the change in the character of the sandstones, which become increasingly massive and conglomeratic by the addition of coarser material as they approach the old shoreline on the east, in harmony with the general law of the region.

Another conspicuous feature is the appearance of bands of gray sandstone above the base of the Bloomsburg near the Delaware River, and especially of the very massive gray sandstones in a zone 571 to 945 feet above its base. At first it seemed possible that the latter sandstones might

[37] The mountain is covered by glacial drift east of Wind Gap, rendering the relationships uncertain east of this point.

be the equivalents of the upper gray sandstones in the section at Lehigh Gap and of the Keefer sandstone farther west, as interpreted by Chance.[38] The constancy of the thickness of the Bloomsburg, the inconstancy of these gray sandstones on the strike, the presence of thick red beds below them, the tracing of the horizons above described from Lehigh Gap to Delaware Water Gap, and the approximate constancy of thickness of the underlying gray beds all militate against that view.

Road leading to Fox Hill Gap.—In the course of this investigation it became very desirable to know the thickness of the Bloomsburg red beds, since this is important for purposes of correlation.

The top of the Bloomsburg is nowhere exposed in the vicinity of the Delaware Water Gap and it seemed unsafe to make assumptions concerning the concealed interval because of the complex folding in the axis of the minor anticline at that place. This anticline rises toward the southwest where the structure becomes simpler. It is intersected 3½ miles southwest of the Water Gap by a gorge, known locally as Wild Cat Hollow, through which runs the county road leading from Cherry Valley to Fox Gap. A section was measured at this gorge, which seems to permit of a more trustworthy estimate than could be obtained elsewhere, though much is concealed. The conglomerates of the Decker Ferry, lying 20 to 40 feet above the base of the Keyser limestone, are exposed on the south side of the Cherry Valley road at the fork of the road leading to Fox Gap, the beds lying practically horizontally at that place. The traverse begins at the junction of the Fox Gap road with the road leading west to Kemmererville and extends southward through the gorge. The rocks are concealed between the Cherry Valley road and the beginning of the traverse—a distance of about 1,800 feet measured at right angles to the strike; their thickness was estimated to be between 800 and 900 feet.

Section along county road

	Horizontal Total	Thickness Beds	Thickness Total
Decker Ferry:			
Massive calcareous conglomeratic sandstone and arenaceous limestone and concealed. About	....	50	.....
Bossardville limestone and Poxono Island shale. Concealed in Cherry Valley. About	....	300	.....
Bloomsburg red beds:			
Concealed across Cherry Valley. Thickness estimated	....	500	1,900

[38] H. M. Chance: Second geological survey of Pennsylvania, vol. G6, 1882, pp. 343-344. He designates them as the "ore sandstone" (Keefer sandstone).

Section beginning at fork of road leading through gap

	Horizontal Total	Thickness Beds	Thickness Total
Concealed. House on east at 230 feet of traverse	480	300	1,400
Red sandstone and shale	540	40	1,100
Concealed	990	315	1,060
Massive red sandstone, seen in stream	1,000	10	745
Massive greenish-gray sandstone exposed in stream, dip 55 degrees north	1,035	35	735
Interbedded greenish-gray and red sandstone and shale partially concealed along road	1,380	225	700
Section in bed and west of stream. Traverse leaves road at 1,250			
Concealed	1,450	50	475
Massive red sandstone and shale, exposed north and south of stone bridge	....	275	425
Concealed. About	....	75	150
Massive red sandstone and shale, its top conglomeratic; exposed east of stream, its base 650 feet south of bridge. Thickness approximate	....	75	75
Total thickness of Bloomsburg red beds, approximately			1,900

Correlation.—Kümmel estimated the thickness of these beds opposite Poxono Island as 2,305 feet.[39] He appears to have included in them the shaly beds above the massive conglomeratic sandstones of the Shawangunk, which are 280 feet thick at Delaware Water Gap, making his estimate of the Bloomsburg about 2,000 feet. The thickness of the beds observed in this region at Rauschs, 1,800 feet; at Lehigh Gap, perhaps 2,000 feet; at Wild Cat Gap, 1,900 feet, and at Poxono Island, 2,000 feet—are in general agreement, indicating that the thickness of the Bloomsburg of this region is approximately 2,000 feet or a little less.

These measurements show, with a high degree of probability, that the variegated red and gray beds of the section at the Delaware Water Gap are parts of the Bloomsburg and do not belong to the underlying Clinton. This conclusion has an important bearing on the correlation of the beds considered.

Delaware Water Gap.—Blue Mountain, in Pennsylvania, undergoes a slight flexure in the neighborhood of the Delaware River. East of the

[39] S. Weller: N. J. Geol. Surv., Paleontology, vol. 3, Paleozoic Faunas. 1903, p. 55.

point of flexure it is called Kittatinny Mountain. The Delaware River in its course southward has cut a deep gorge through this mountain, making a superb exposure of the rocks under consideration.

The sections described are at two localities: (1) along and west of the State highway running through the gorge, and (2) in the cuts of the Delaware, Lackawanna & Western Railroad east of the highway.

The traverse begins at the southern end of the gorge and extends northward. The measurements along the road are given in terms of the stations of the Pennsylvania State highway survey, marked along the road.

Section along hillsides and in golf courses west of highway

	Horizontal Total	Thickness Beds	Thickness Total
Bloomsburg red beds:			
Concealed across Cherry Valley. Estimated about	....	700	1,964
Red sandstone and shale, partially concealed. Interbedded in the lower part are some lenticular beds of greenish-gray argillaceous sandstones that are inconstant on the strike. A very massive bed of this character is seen opposite the Methodist Church in the village. Thickness of this unit is about	....	300	1,264

Section along tracks of Delaware, Lackawanna & Western Railroad north of railroad station

The traverse begins at center of anticline 427 feet south of center of station. Center of bridge over Cherry Creek is 2165 of traverse.	....	.....	.....
Greenish-gray sandstone 8 inches thick at top. Concealed below	1,670	19	964
Massive greenish-gray sandstone,[40] courses up to 4 feet thick, and some shale. This sandstone is seen at fork of road in village	1,630	60	945
Concealed	1,505	85	885
Massive greenish-gray sandstone[40] and some shale	1,323	42	800
Concealed	1,230	88	758
Massive greenish-gray sandstone,[40] courses up to 3 feet thick, and some shale. Its base is 810 feet of traverse on railroad	1,045	99	670

[40] A. B. and C. sandstones of H. M. Chance (Second Geol. Surv. of Pa., vol. G6, 1882, pp. 343-344), believed by him to be the equivalents of the Keefer ("Ore") sandstone.

Section exposed in cliff beneath the Kittanning Hotel, 80 feet south of hotel and in cliff opposite hotel. Its bottom is at level of railroad

	Horizontal Total	Thickness Beds	Thickness Total
Interbedded red and greenish-gray sandstone and shale, many beds massive. The lowest sandstone of preceding section is seen at top of cliff and about Lake Lenape.....	....	114	571

Section exposed along D. L. & W. R. R. in south limb of an anticline. Its base is at center of anticline 427 feet south of center of railroad station

Interbedded red and greenish-gray sandstone and shale. Concealed south of this point on railroad	....	182	457

Section seen along State highway [41]

Traverse begins at south end of gorge and extends northward, the measurements being to tops of units.	....	.....	.....
Massive red sandstone. A bed of gray sandstone 3 feet thick, 60.5 to 63.5 feet above base of unit.....	31310	121	275
Gray conglomeratic sandstone.....	.....	10	154
Red sandstone and shale, containing a bed of hard gray sandstone 3 feet thick, 87 to 90 feet above base of unit.....	31595	144	144
Thickness of Bloomsburg formation described			1,264
Shawangunk formation:			
Greenish argillaceous sandstone above. Concealed below.....	31918	9	1,823
Greenish-gray sandstone, somewhat conglomeratic. Some greenish-gray shale at base..	31940	64	1,814
Concealed	32035	206	1,750
Massive hard gray sandstone somewhat conglomeratic. The upper part of this unit is seen in the cut of the D. L. & W. R. R. This is Chance's bed number 3.[42] The road turns sharply to the west at 33306.....	32370	346	1,544
Concealed. A bed of hard gray conglomeratic sandstone is present in this unit, its base 102 feet above base of unit.....	33040	268	1,198

[41] Minor folds complicate the section, making it difficult to follow the beds. The section here given has been checked by detailed measurements and is believed to be essentially correct.

[42] H. M. Chance: Second geological survey of Pennsylvania, vol. G6, 1882. p. 345.

	Horizontal Total	Thickness Beds	Thickness Total
Massive gray conglomeratic sandstone and some thin beds of black arenaceous shale. Pebbles average ¼ to ½ inch in diameter, some much larger. Some black shale pebbles. This is Chance's bed number 2. About its center Van Ingen collected *Dolichopterus otisius, Eurypterus maria, Stylonurus* cf. *myops, Hughmilleria shawangunk, Pterygotus* cf. *globiceps.*[43]	34400	222	930
Thin-bedded arenaceous shale, concealed at top	34940	64	708
Greenish-gray arkosic sandstone	35040	102	644
Concealed	35200	310	542
Massive gray conglomeratic sandstone. Pebbles up to ½ inch diameter common. Forms a great cliff at south end of gap. Its base well seen on New Jersey side of river. (The Northampton-Monroe County line is at 35684 of traverse)	35700	232	232
Total thickness of Shawangunk formation[44]			1,823
Martinsburg shale:			
Concealed above. Greenish-gray argillaceous sandstone and dark-gray shale of great thickness are exposed below	36050	.....	.....

Correlation.—Three massive sandstone zones are manifestly present in the Shawangunk in this section, lying 0 to 644 feet, 708 to 930 feet, and 1,198 to 1,544 feet above the base of the section, respectively, the lower 232 feet being particularly massive.

As has been shown in the preceding discussion, three corresponding sandstones can be recognized beneath the Bloomsburg, in the section on the Lehigh River. The lowest zone is formed by the Tuscarora at the Lehigh, 0 to 457 feet above the base of the section; the middle zone is the zone of very massive gray sandstones, associated with iron sandstones, in the Rose Hill, 806 to 1,047 feet; the upper zone is the massive sandstone zone 1,230 to 1,455 feet above the base of the section, representing

[43] J. M. Clarke and R. Ruedemann: N. Y. State Mus., Mem. 14, 1912, pp. 414-418.

[44] The propriety of referring the upper 279 feet to the Shawangunk may be questioned in view of the thick concealed interval at its base. The portion that is assuredly Shawangunk is 1,544 feet thick.

the upper Clinton (possibly, in part, the Keefer) sandstone. The lower 240 feet of the section are also more massive.

These three sandstone zones can be followed east along the mountain from Lehigh Gap to the Delaware Water Gap, the Clinton sandstone becoming more massive and finally conglomeratic in approaching the Delaware River, where they unite, as has been shown on page 30 of this MSS., to form the Shawangunk of the Delaware Water Gap. The Bloomsburg also can be traced continuously above the Clinton and Shawangunk.

SECTIONS IN NEW YORK

Otisville.—No good sections were obtained between Delaware Water Gap and southeastern New York. Sections were studied in the vicinity of Otisville, New York, at three localities on the Erie Railroad as follows: (1) three-quarters of a mile west of Otisville, (2) at the stone crusher 1¾ mile south of the preceding section, (3) three-quarters of a mile south of Graham station, 5 miles southwest of Otisville.

Section seen in bed of small rivulet that crosses railroad tracks 3/4 mile south of Graham Station, near telegraph pole 80.17, and flows into Watts Pond

	Thickness	
	Beds	Total
The section begins 425 feet east of tracks and extends westward.		
Bloomsburg red beds:		
Concealed west of railroad tracks.....	.....	.....
Red sandstone and shale with some green bands. Massive gray sandstones were seen 62 to 70 feet and 234 to 240 feet above the base of the section.....	349	349
Thickness of Bloomsburg red beds described		349
Massive gray conglomeratic sandstone is exposed at base of red beds 425 feet east of the railroad tracks	.....	.....

Section exposed on Erie Railroad at stone crusher 1 3/4 miles southwest of Otisville, south of milepost 76

Massive gray conglomeratic sandstone is seen in ravine which crosses the railroad at this point. The traverse begins at the top of this conglomerate and extends westward to the railroad tracks and thence northward along the track.

Shawangunk formation.

Otisville shale member.

Section exposed along railroad tracks

	Traverse Total	Thickness Beds	Thickness Total
Concealed northward.....	....	.....	.....
Interbedded greenish-gray arkosic sandstone and arenaceous shale. Some of the sandstone is conglomeratic. Beds much stained by limonite	....	40	484
Traverse 90 degrees to strike			
Concealed	690	54	444
Beds similar to those described above.....	615	29	391
Traverse 61 degrees to strike			
Beds similar to those described above.....	575	145	362
Concealed. Arkosic sandstone 2 feet thick 127 to 129 and 8 feet thick 155 to 163 feet above base of unit.....	345	217	217
Total thickness of Otisville shale member described			484

Section 3/4 mile west of Otisville

The section is exposed along the Erie Railroad beginning ½ mile west of Otisville, New York, and extending westward along the track, and in a quarry formerly operated by the railroad company. The upper beds are seen along the state highway west of the railroad quarry.

The contact of the Shawangunk with the underlying Ordovician shale is finely shown in cut east of sharp turn of State highway to left in going east. The shale dips 37 degrees and the conglomerate 25 degrees west. The measurements of these beds are those of Schuchert.[45]

	Thickness Beds	Thickness Total
Shawangunk conglomerate:		
Conglomeratic beds:		
Massive white cross-bedded conglomeratic sandstone with numerous interbedded bands of black arenaceous shale. Eurypterids are abundant in the shale 420 feet above the base, including *Dolichopterus otisius, D. stylonuroides, Eurypterus maria, Eusarcus? ciccrops, Hughmilleria shawangunk, Pterygotus globiceps, P. cestrotus* r, and *Stylonurus myops.*[46].....	.....	.....

[45] Charles Schuchert: Bull. Geol. Soc. Amer., vol. 27, 1915, p. 544.

[46] J. M. Clarke and R. Ruedemann: N. Y. State Mus., Mem. 14, 1912, pp. 87-88. Sections are given also on pp. 104-105.

	Thickness	
	Beds	Total
Arthrophycus alleghaniensis is also abundant 28 feet below the top of the unit west of State highway and on loose blocks in quarry 450 feet above base of unit	650	650
Total thickness of gray conglomeratic sandstone		650

Correlation.—The relation of the sections at Otisville, New York, to the section at the Delaware Water Gap, Pennsylvania, has already been discussed by various workers and the evidence need not again be presented here.

The Shawangunk of the Delaware contains five species of Eurypterids, found in black shale bands in massive gray conglomeratic sandstone. The conglomerate beds may be followed without break northeastward from the Delaware River in the continuation of Kittatinny Mountain and northward in Shawangunk Mountain to Otisville, New York. At that place the same five species of Eurypterids are found in black shale bands in massive gray conglomeratic sandstones resembling in all respects, lithologically, the corresponding beds of the Delaware. Their identity may be considered well established.

High Falls.—The most northerly section studied is that at High Falls, New York. The exposure is below the Falls on Rondout Creek, about 34 miles northeast of Otisville and 10 miles southeast of the Hudson River. The following section was measured there:

	Thickness	
	Beds	Total
Binnewater sandstone:		
Thin-bedded calcareous ripple-marked sandstone above, greenish arenaceous shale below. The upper foot, an arenaceous limestone	36	36
Total thickness of Binnewater sandstone		36
High Falls shale:		
Variegated shale and limestone member		
Shale, gray, calcareous above; greenish, arenaceous below	6.5	46
Red and green arenaceous shale with 3 feet of variegated arenaceous limestone 2.5 to 5.5 feet above base	17	39.5
Green arenaceous shale with mud cracks	3	22.5

	Thickness	
	Beds	Total
Compact arenaceous limestone forming ledge across top of lower falls. Upper beds laminated, ripple marked, with mud cracks	7.5	19.5
Green arenaceous shale, 1-foot red shale near base	12	12
Total thickness of variegated beds		46
Red shale member		
Red shale with some thin green bands. Thickness about	50	50
Concealed short interval	.....	.....
Total thickness of High Falls shale measured		96
Shawangunk formation:		
Massive gray conglomeratic sandstone, its upper beds[47] exposed in creek. Concealed below. Thickness about	.....	270

Correlation.—Although glaciation has covered much of the region underlain by the Bloomsburg red beds north of the Delaware Water Gap, and although the Delaware has cut its bed in them, nevertheless exposures are sufficiently numerous to enable one to trace them from the Delaware Water Gap to Otisville and High Falls, and thus to establish their continuity throughout this region. Stose has accordingly called them the High Falls beds at Delaware Water Gap.[48] They are the Medina-Longwood sandstones of the New Jersey Geological Survey.[49] Their identity throughout the region may be considered established.

Conclusions

General statement

The examination of the above described sections leads to certain clearly defined conclusions that may be stated as follows:

Tuscarora-Clinton

Faunas.—The Silurian sequence observed in Maryland may be traced eastward to Loysville and Danville, Pennsylvania. At these places are found the same formations that occur in Maryland, comparable in thickness and containing the critical faunal zones described above. Although

[47] T. C. Brown: Amer. Jour. Sci., vol. 37, 1915, p. 469.

[48] G. W. Stose: U. S. Geol. Surv., Text on back of topographic map of Delaware Water Gap quadrangle, 1922.

[49] S. Weller: N. J. Geol. Surv., Paleontology, vol. 3, 1903, pp. 55-56.

fossiliferous limestones and shale zones are concealed in the sections north of Harrisburg, Pennsylvania, the proximity of the section to that at Loysville (distant 25 miles) and the similarity in thickness of beds, sequence, and lithology make the correlation of the sections sufficiently conclusive. The Silurian sequence of Maryland may thus be traced as far east as the Susquehanna River.

East of the Susquehanna the beds become increasingly arenaceous and barren. Nevertheless, certain critical marine faunal zones are found as far east as Swatara Gap. Here the *Drepanellina ventralis* zone of the Upper Rochester is clearly developed with its characteristic species. Below is a zone with *Rhipidomella hybrida* of the *Dalmanites limulurus* fauna of the Rochester, and below the latter is a more meager Rose Hill-Clinton fauna.

In the Rose Hill and in the Tuscarora are beds containing the Eurypterid species common in the Shawangunk at Otisville, New York. The intertonguing of these Eurypterid faunas with the marine faunas fully fixes their age as Clinton and Medinan. Both the Tuscarora and Rose Hill of this locality contain all the species common in the Shawangunk at Otisville, New York, represented, in all but one species, by carapaces, and identified by Clarke and Ruedeman. The same species are found also in the Shawangunk at the Delaware Water Gap, which is continuous with the Shawangunk at Otisville, New York.

The faunal evidence seems therefore clearly to fix the age of the Shawangunk as either Tuscarora or Clinton or both. It is clearly pre-Cayugan and pre-Salinan.

Sequence and lithology.—An examination of the stratigraphic sequence and lithology leads to the same results.

The Tuscarora sandstone may be traced eastward beneath the Clinton without interruption from Maryland to Lehigh Gap. At the latter point it has become conglomeratic, very massive, and has assumed the Shawangunk facies. East of Lehigh Gap it has been shown to persist beneath the shale to the Delaware Water Gap, where it merges with the basal beds of the Shawangunk. At no point in the mountain does the Tuscarora cease and the Shawangunk begin.

The Rose Hill is very shaly westward, where it bears a rich and varied fauna to within a few miles of the Susquehanna River. It becomes increasingly arenaceous eastward.

Two zones of iron sandstone appear in the Rose Hill as it approaches the Susquehanna River, affording a valuable means of correlation. The upper iron sandstone zone appears west of Loysville and extends east to

Swatara Gap. The lower and thicker zone is well shown in the Susquehanna Gap north of Harrisburg. It extends east to Lehigh Gap where it is very massive and is associated with gray sandstones. Its top is about 1,000 feet above the base of the Tuscarora at Lehigh Gap. The iron sandstones were last seen at Smith's Gap, 10 miles farther east. The gray sandstones found in this zone thicken and become conglomeratic eastward and appear to form the middle beds of the Shawangunk conglomerate at Delaware Water Gap.

The Rochester formation consists of an overlying limestone and shale member above and the Keefer sandstone below, at the west. Eastward the shale member thins, though it still carries a rich and varied Rochester fauna at Loysville and Danville. At Swatara Gap it still carries the diagnostic Upper Rochester fauna, but has become almost wholly sandy and merges with the underlying sandstones.

The Keefer sandstone is but 8 feet thick at Cumberland. At Loysville it is 50 feet thick, and the overlying shale has become correspondingly thin. It seems to persist eastward and may perhaps be represented, in part, by the upper massive sandstone at Lehigh Gap. The latter becomes conglomeratic farther east and merges with the upper sandstone of the Shawangunk at the Delaware Water Gap.

The Rochester and Rose Hill thus clearly combine east of the Susquehanna, as they do in the typical Clinton area in New York, to form one formation, the Clinton, consisting of the united Rochester and Rose Hill. Farther east the Clinton becomes more arenaceous and conglomeratic, and unites with the Tuscarora to form the Shawangunk at the Delaware Water Gap. This can be traced thence to southeastern New York at Otisville and finally to near Rondout on the Hudson.

Both faunal and stratigraphic evidence thus combine to show that the Shawangunk is the united Clinton and Tuscarora at the Delaware River.

What the relationship of the Otisville shale member of the Shawangunk is to the deposits observed elsewhere is not unknown. A similar shale occurs above the conglomerates at the Delaware Water Gap, but their relationship is unknown.

McKENZIE-CAYUGAN

The problem presented by the Bloomsburg red beds is one of unusual interest, but it lies beyond the limits of this paper except as it bears upon the correlation of earlier beds.

It is clear that the Bloomsburg is of more than one age. Like the Catskill and similar red deposits, it begins at different times and ends at

different times in neighboring areas. In western Maryland it is but 36 feet thick at Cumberland and is still thinner southwestward. Eastward, red tongues appear in the overlying Wills Creek which thicken and finally merge both with each other and with the underlying Bloomsburg. In the same region red beds appear in the underlying McKenzie, which also merge with the overlying strata eastward until finally the Bloomsburg of the east comes to represent the whole of the Wills Creek, the Bloomsburg of the west, the upper half of the McKenzie or possibly the whole of the McKenzie,[50] and probably the basal Tonoloway. It attains a thickness of approximately 2,000 feet in eastern Pennsylvania.

It is thus manifest that the Bloomsburg is a lithological phase—not a geological age. It accumulated on the continental margin to the east, while different marine deposits were formed to the west. It also probably has climatic significance, since imprints of salt crystals are found in the Wills Creek of western Maryland, and salt is contained in beds of similar character in central New York. Still farther east the Bloomsburg thins as it does westward.

The Bloomsburg was named by White from its occurrence in northeastern Pennsylvania.[51] As has been shown, it can be followed continuously from its type locality southward into Maryland and eastward through central and eastern Pennsylvania to the Delaware Water Gap, where it was called by Chance[52] the Clinton and by Stose[53] the High Falls. It is continuous with the Medina-Longwood red sandstone of New Jersey[54] and the High Falls red beds of Hartnagel[55] in southeastern New York. It is manifest that it is the same formation throughout this entire area and should have one name to avoid confusion. The term Bloomsburg has priority.

The relations of the Bloomsburg with the deposits of central New York are as follows: The Bloomsburg descends from its type region in northern Pennsylvania under the synclinal trough lying to the north. A deposit, similar in every respect and having similar stratigraphic relationships, emerges from beneath the trough in central New York, where it is called the Vernon red shale.

[50] Whether any of the McKenzie extends eastward as gray beds beneath the Bloomsburg can not now be told. If it does, it is thin, since the Rochester fauna is found in sandstones within 125 feet of the base of the Bloomsburg at Swatara Gap.

[51] I. C. White: Second geological survey of Pennsylvania, vol. G7, 1883, pp. 104, 106.

[52] H. M. Chance: Second geological survey of Pennsylvania, vol. G6, 1882, pp. 342-344.

[53] G. W. Stose: U. S. Geol. Surv., Topographic map of Delaware Water Gap, 1922, text on back of map.

[54] S. Weller: N. J. Geol. Surv. Paleontology, vol. 3, 1903, pp. 55-56.

[55] C. A. Hartnagel: N. Y. State Mus., Bull. 80, 1905, p. 345.

The Bloomsburg of Maryland is overlain by the Wills Creek shale which contains imprints of salt crystals and merges eastward with the underlying Bloomsburg. The Vernon of New York is overlain by the Camillus shale of approximately the age of the Wills Creek; it is associated with salt deposits, and appears to thicken eastward. The similarity of their stratigraphic relations, the likeness of the sections, their intertonguing with beds of like geological age in both areas, the likeness of climatic conditions in immediately contiguous areas as indicated by the salt deposits, their passage under the syncline in both areas, and the fact that red beds are not strictly of one age, all unite to show that the Vernon and Bloomsburg are the same formation.

Summary

The foregoing discussion may be summarized as follows:

1. The early Silurian formations of Maryland were deposited in the same basin and are continuous with the early Silurian deposits of eastern Pennsylvania and southeastern New York. The Rochester and Rose Hill-Clinton of Maryland contain a rich and varied fauna that permits of their correlation with the corresponding formations of western New York. These facts provide a basis for the correlation of the nearly barren deposits of eastern Pennsylvania and southeastern New York with the formations of western New York.

2. The Rochester and Rose Hill possess a rich and abundant fauna as far east as the Susquehanna River, but east of the river they become increasingly barren. At Swatara Gap both the Rose Hill-Clinton and the Tuscarora contain Shawangunk Eurypterids, all but one of the species common at Otisville, New York, occurring in both formations, beneath a well defined Upper Rochester fauna.

3. In passing eastward through Pennsylvania both the Rochester and Rose Hill become increasingly arenaceous. East of the Susquehanna River the Rochester loses its calcareous beds, and the two divisions of the west fuse to make a single lithological unit, the Clinton formation, embracing, as in eastern New York, both the Rochester and Rose Hill-Clinton.

4. The Tuscarora and Clinton may be followed in rather closely placed sections from Maryland eastward to Lehigh Gap, Pennsylvania. Here the Tuscarora has become very conglomeratic and assumed a Shawangunk facies.

5. East of Lehigh Gap the Clinton also becomes conglomeratic. Three sandstone horizons may be traced from the Lehigh to the Delaware

beneath the Bloomsburg. The lowest, the Tuscarora, is found to merge with the lower Shawangunk conglomerate at the Delaware. The massive sandstone zone of the Middle Clinton passes into the middle Shawangunk conglomerate, and the upper sandstone zone, representing possibly the western Keefer (Rochester) sandstone, unites with the Upper Shawangunk conglomerate of the Delaware. The Shawangunk of the Delaware Water Gap therefore represents the combined Tuscarora and Clinton farther west.

The Shawangunk of the Delaware Water Gap is lithologically like that at Otisville. Also it contains all the common species of the Otisville Eurypterid fauna, and may be traced continuously until it merges with the Shawangunk at Otisville, New York.

6. The Bloomsburg red beds thicken eastward, being a continental deposit, representing marine formations farther west. This formation replaces in turn the Wills Creek, Bloomsburg, upper part of the McKenzie, possibly the entire McKenzie, and perhaps the lower part of the Tonoloway of the west. It is continuous with the Longwood of New Jersey and the High Falls red beds of eastern New York. It is believed to be the same as the Vernon red shales of central New York and that all these continental formations should bear one name.

Explanation of Figure 2

General statement

The sections are represented by vertical lines, interrupted where beds are concealed. The distances shown between the sections are measured parallel to the strike of the mountain structures.

Sections[58]

I. Cumberland, Maryland. Measurements by W. F. Prouty and C. K. Swartz. Ostracod zones by E. O. Ulrich.

II. West of Hancock, Maryland, by C. K. Swartz and W. F. Prouty. Tonoloway at Grass Hopper Run, West Virginia; Wills Creek at Round Top, Maryland; McKenzie and Rochester, east of Tonoloway, Maryland; Rose Hill at Great Cacapon, West Virginia.

III. West of Fairview Mountain, Maryland, by C. K. Swartz. Tonoloway, northwest of Indian Spring; Wills Creek, west of Clear Spring; McKenzie at Rabble Run; Rose Hill at Hanging Rock.

IV. Marklesburg, Pennsylvania, by Ulrich and Butts.

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[58] See Maryland Geol. Surv., Silurian, 1923, for descriptions of sections in Maryland and West Virginia.

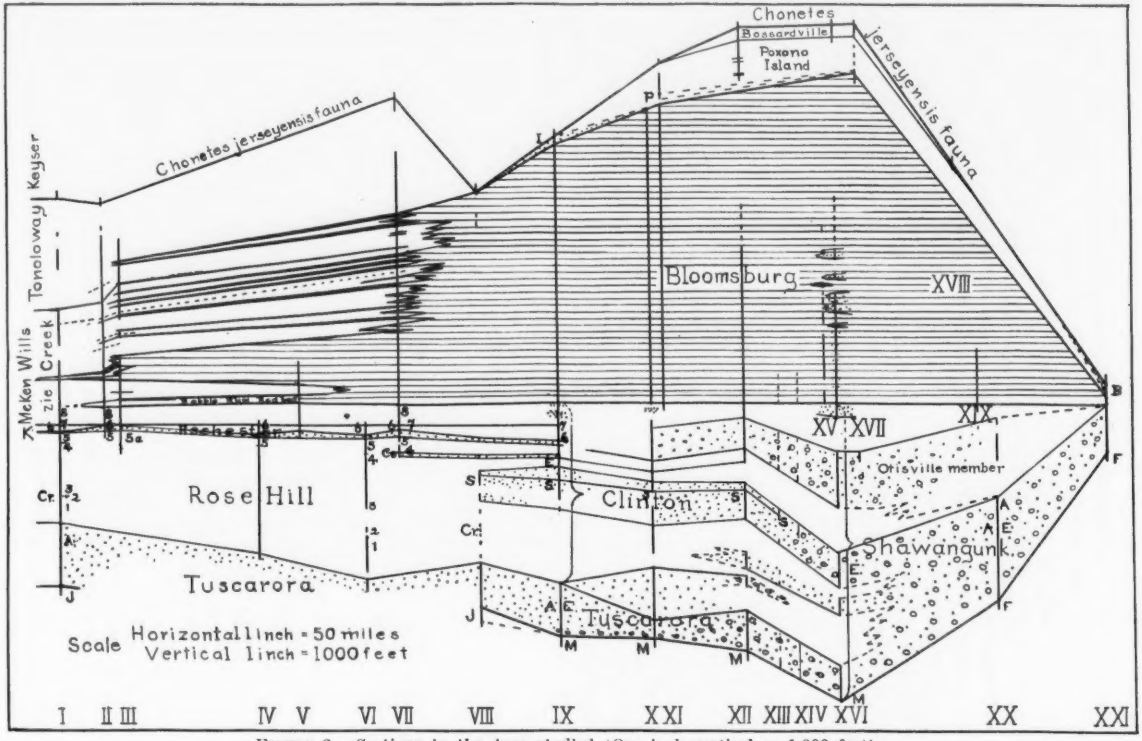

FIGURE 2.—*Sections in the Area studied* (One inch vertical = 1,000 feet)

V. Saltillo, Pennsylvania, by Ashburner.
VI. Honey Grove, Pennsylvania, by Ulrich and Butts.
VII. Loysville, Pennsylvania, by C. K. Swartz and F. M. Swartz.
VIII. North of Harrisburg, Pennsylvania, by C. K. Swartz and F. M. Swartz.
IX. Swatara Gap, Pennsylvania, by C. K. Swartz and F. M. Swartz.
X. Schuylkill Gap, Pennsylvania, by C. K. Swartz and F. M. Swartz.
XI. Rausch, Pennsylvania, by C. K. Swartz and F. M. Swartz.
XII. Lehigh Gap, Pennsylvania, by C. K. Swartz and F. M. Swartz.
XIII. Smiths Gap, Pennsylvania, by C. K. Swartz and F. M. Swartz.
XIV. Wind Gap, Pennsylvania, by C. K. Swartz and F. M. Swartz.
XV. Road to Fox Gap, Pennsylvania, by C. K. Swartz and F. M. Swartz.
XVI. Delaware Water Gap, Pennsylvania, by C. K. Swartz and F. M. Swartz.
XVII. Poxono Island, Pennsylvania, by I. C. White.
XVIII. Nearpass Quarry, New Jersey, by Stuart Weller.
XIX. Graham Station, New York, by C. K. Swartz and F. M. Swartz.
XX. Otisville, New York, by C. K. Swartz, F. M. Swartz, and Charles Schuchert.
XXI. High Falls, New York, by C. K. Swartz, F. M. Swartz, and T. C. Brown.

FAUNAL ZONES

1. *Zygobolba decora* zone.
2. *Zygobolbina emaciata* zone.
3. *Mastigobolbina lata* zone.
4. *Bonnemaia rudis* zone.
5. *Mastigobolbina typus* zone.
5a. *Liocalymmene clintoni-Chonetes novascoticus* zone.
6. *Dalmanites limulurus-Drepanellina clarki* zone.
7. *Whitfieldella marylandica-Drepanellina ventralis* zone.
8. *Orthoceras mackenzicum-Hormatoma* zone.

A—*Arthrophycus alleghanensis.*
E—*Eurypterids.*

LITHOLOGIC DIVISIONS

B—Binnewater sandstone.
Ce—Center iron sandstone.
Cr—Cresaptown iron sandstone.
F—Frankfort shale.
I—Inwood sandstone.
J—Juniata sandstone.
K—Keefer sandstone.
M—Martinsburg shale.
P—Poxono Island limestone.
S—Swatara Iron sandstone.

Sections in the Area studied (One inch vertical = 1,000 feet)

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MINFORD SILTS OF SOUTHERN OHIO

BY WILBER STOUT AND DOWNS SCHAAF

(*Prepared for the Society, December, 1930.*[1])

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INTRODUCTION

Throughout southern Ohio and in adjacent parts of West Virginia and Kentucky, the preglacial drainage lines are all much choked with highly laminated silt, fine sand and, very locally, a coarse rubble. In Ohio, south of the glacial drift, such old valleys are clearly defined by certain topographic features and also by the character of the deposits in them. Even far north of the terminal moraine, where they are occasionally exposed for examination, these old stream beds exhibit in many places along the walls large masses of characteristic silt, these bodies being remnants of the original filling that escaped destruction by glacial action. In general, these highly laminated silts are best developed along the old Kanawha or

[1] Not presented at the Toronto meeting as intended, because a part of the analytical work was not completed at that time. Permission to print in Volume 42 granted by the Publication Committee of the Geological Society. Manuscript received by the Secretary of the Society February 10, 1931.

Teays system, evidently the master stream of the region, the headwaters of which were far to the southward. Such material is found not only along the main waterways of this old drainage system, but also far up the smaller tributaries. The deposits are best represented, because they have been least disturbed, in the parts of these valleys that now form divides between present streams and in the parts that were abandoned through piracy, meanders and other readjustments.

Extent of Deposits

In southern Ohio, south of the drift border, the largest of these old, highly silted preglacial streams are the Kanawha or Teays, Portsmouth, Marietta and Albany. The Kanawha or Teays, the master stream, rose in Virginia, flowed across West Virginia and then into Ohio past Ironton, Wheelersburg and Waverly to Chillicothe, where it is buried by glacial debris. The headwaters of the Portsmouth River, the largest western tributary, were near Manchester in Adams County. It flowed eastward to Portsmouth, then northward to Waverly, where it joined the Teays. The main eastern tributary of the Teays was the Marietta River, which in itself was a rather large system, as it drained a wide area in southern Ohio and in north central West Virginia. In Ohio its gathering basin extended to Sardis and Woodsfield, Monroe County, to Caldwell, Noble County, and to Eagleport in Morgan County. The main stream flowed southwestward from Marietta past Belpre, Coolville, Pomeroy, Gallipolis and Jackson to Beaver where it united with the Teays. The Albany River rose in southern Perry County, flowed southward past Athens, Albany, Wilkesville and Vinton, and then joined the Marietta at Rio Grande. The smaller tributary streams also contain great quantities of silt of the same general character as that found along the larger courses. In fact such material is not only widely distributed but occurs in great quantities.

The area in the Teays system alone in which these fine-grained laminated silts are so conspicuous thus includes nearly 7,000 square miles in Adams, Scioto, Pike, Lawrence, Jackson, Vinton, Hocking, Gallia, Meigs, Athens, Perry, Washington, Morgan, Noble and parts of several other counties. Undoubtedly similar conditions as to drainage and silting were present far to the northward in what is now the glaciated area. Silts very similar in texture and composition are also found in the old Monongahela drainage system in eastern Ohio, northern West Virginia and western Pennsylvania, and also in other systems to the west.

Elevation of Deposits

In the Kanawha or Teays basin of southern Ohio, the upper limit of these fine-grained highly laminated silts appears to be about 820 feet above tide, but ordinarily the main deposits are not often found above 780 feet. The lower limit, of course, is the floor of these old streams at any given place. At Chillicothe, where the channel of the old Teays River passes under the terminal moraine of the Wisconsin drift, the rock floor is approximately 620 feet above tide. Toward the headwaters in this stream and in its larger tributaries the floor rises normally from 8 inches to 1 foot per mile, or from 620 to about 680 feet. In the smaller streams the gradient is much higher but the floors are silt laden until they pass above the 800-foot level. The relative positions of these fine-grained silt deposits along old divides where they have been least disturbed are, for example, 680 feet at Londonderry, Ross County; 680 feet at Beaver, Pike County; 680 feet at Wheelersburg, Scioto County; 700 feet at Keystone, Jackson County; 720 feet at Wilkesville, Vinton County; 760 feet at Olive Furnace, Lawrence County; 700 feet at Rodney, Gallia County; 750 feet at Tuppers Plains, Meigs County; 765 feet at Albany, Athens County; and 760 feet at Barlow, Washington County. The main deposits along the larger streams thus fall between 650 and 780 feet.

Character of Deposits

General statement

The deposits in these old valleys vary considerably from place to place, owing partially to original deposition and partially to removal and change since the time of formation. No regular succession is evident but the most common arrangement is sand and sandy silts near the bed rock and the fine, laminated silts at the higher levels. The materials that may be present in the deposits in these old valleys are coarse matter, fine-grained sands, siliceous and ferruginous clays, highly laminated, fine-grained silts and heterogeneous outwash from side streams.

Coarse material

The coarse matter consists of sandstone boulders, highly weathered chert and quartz pebbles. In general, such materials are far from abundant and in many sections are absent. Where present these deposits lie on or near the bed rock. At some places the chert and quartz pebbles are scattered through the sandy clays in the lower part of the formation. The chert is always highly leached and discolored, few of even the largest

pieces showing a core of unaltered material and usually the surface is highly polished from abrasion. Fossil evidence indicates that this chert is derived from limestone along the course. The quartz pebbles may also be assigned to conglomerates and conglomeratic sandstones that outcrop well within the basin. The boulders range in size from 1 to 6 inches and are well rounded from stream action. They are only firmly cemented sandstones such as may be gathered from the coal formations throughout the basin. Most of these materials, therefore, may be assigned to the normal rocks of the region.

SANDS

Most of the sand deposits lie directly on the bed rock, but a few of them are more or less interbedded with the siliceous or with the highly laminated silts. These sands are fine to medium in texture, have well-rounded grains and are stained yellow with iron oxide coatings. They contain a few per cent of mica and clay matter, part of which acts as a bonding component. Such sands are similar in character to deposits along the present streams that lie beyond the influence of the glacial drift.

Locally, above the sands, occur deposits of rather siliceous silts which appear to be the old alluvium along the preglacial streams. This material is fine in texture, is blue to gray in color, depending upon the state of oxidation, has a fair plasticity and in general is very siliceous in composition. Such deposits show considerable variation in character from place to place. On the whole, however, they are not far different from the alluviums along the larger streams which are active within this area and the deposits of which are little modified by glacial outwash.

LAMINATED SILTS

General Statement.—The most outstanding deposits in these old preglacial valleys are the highly laminated silts which rest on the sands and alluviums and which, with local fans of outwash from side streams, form the upper part of the valley filling. Unless modified by erosion, these silts make up by far the greater part of the formation. Such deposits are widely distributed throughout the entire basin, being present locally on the small tributaries as well as on the main streams. Further, they show marked uniformity as to physical and chemical properties both laterally and vertically throughout the range of deposition. The thickness of these silts on the old divides, that is, where they are least disturbed, is from 10 to possibly more than 80 feet, but usually the measurements range between 20 and 40 feet.

These silts are always highly laminated, the laminae being closely and regularly spaced. When moist the material will peel easily and smoothly along these planes. These silts are made up of very fine-grained particles. When soaked in water the mass readily breaks down to a thin slip. Further, on agitation, the particles are so fine that they may stay suspended for days. Very little coarse material is present and this is largely secondary in origin, such as gypsum crystals and small ferruginous concretions. In the semimoist condition the material is tough and leathery in consistency. It parts readily along the laminations but tears stubbornly when broken across the bedding. When dry it is as hard and firm as some of the older shales. Rubbed with a cloth or with the hand, the surface of the material takes on a smooth, glossy polish. Upon the addition of the proper amount of water these silts have a very high plasticity as measured by most of the standard methods for determining that property. The plasticity, however, is somewhat false in that it is of the soapy, greasy kind instead of the sticky type. The feel of the material, either wet or dry, is soft and smooth like that of finely divided muscovite. For ease of identification and because of the excellent exposure in the cut of the Chesapeake & Ohio Railway at Minford in Harrison Township, Scioto County, this particular silt is here named Minford.

Chemical analyses.—A chemical analysis of these silts show them to be characterized by a high content of potassium oxide, K_2O, and by a higher percentage of alumina, Al_2O_3, than is ordinarily present in shale or alluvium. Three complete analyses made by Downs Schaaf show the range in components in representative material.

	No. 1	No. 2	No. 3
Silica, SiO_2	57.35	53.40	50.02
Alumina, Al_2O_3	24.16	28.08	23.10
Ferric oxide, Fe_2O_3	5.25	4.50	7.08
Ferrous oxide, FeO	...	...	1.16
Titanic oxide, TiO_2	.80	.75	.74
Phosphorous pentoxide, P_2O_5	.11	.10	.75
Manganous oxide, MnO	.03	.02	.05
Lime, CaO	.48	.66	.86
Magnesia, MgO	1.46	1.94	2.80
Potassium oxide, K_2O	4.84	4.40	4.40
Sodium oxide, Na_2O	.10	trace	3.43
Carbon, C	.10	.50	.05
Carbon dioxide, CO_2	none	.30	.04
Sulphur, S	...	...	.015
Water, hydroscopic, H_2O	5.10	5.13	2.77
Water, combined, H_2O			3.23

In the above analyses the chromic oxide, Cr_2O_3, vanadic oxide, V_2O_3, and barium oxide, BaO, are less than .01 per cent.

No. 1.—Sample from Teays Valley, northeast quarter section 18, Seal Township, Pike County.

No. 2.—Sample from tributary of Teays River, east central section 25, Union Township, Pike County.

No. 3.—Sample from Teays Valley, south central section 33, Madison Township, Scioto County.

Through inspection of Minford silts by simple means, some information may be obtained regarding their mineral content and their general composition. They appear to contain but little free silica, practically all of the silica being combined with other components to form complex silicates. No grit is evident when the silt is tested between the teeth or by other common methods. The fineness of grain, shown by the smoothness of the silt, by the ease with which it takes a polish and by the extended time of its suspension in water, shows that the minerals are of only such kinds as may readily be reduced by natural means to a high state of division. The soapy, greasy plasticity of the material when wet is more suggestive of the properties of finely divided micas than of the real stickiness of the truly plastic bodies such as ball clay. Its marked absorptive properties indicate a large surface area per unit volume of material. These characteristics alone are sufficient to separate these silts from the common alluviums, shales and varve clays. The Minford silts are radioactive.

Microscopic analysis.—A microscopic study of the Minford silts by Dr. William J. McCaughey of Ohio State University showed them to contain more than 50 per cent of sercitic mica in a well-preserved condition. Accessory minerals are not abundant, the chief ones being rutile and chlorite. Free silica is present only in very minor quantities. Another outstanding feature of these silts, as shown by the microscope, is the extreme fineness and uniformity of grain. Less than 1 per cent of the grains are more than 5 microns in diameter, placing them in the class of fine silt or clay. The amount of sorting is thus evident and the degree of fineness shows the quiet conditions of the waters in these old channels during deposition.

Conditions of Deposition

The question next arises as to what were the conditions that caused the deposition of such thick deposits of specialized material throughout these preglacial valleys. A review of the main features is helpful in forming

a conclusion. The Minford silts are distributed throughout all the large valleys and well towards the headwaters of the smaller tributaries; they spread entirely across the valleys with no breaks from stream action; they exhibit no marks of strong currents; they are exceptionally fine grained, being in the class of clays; they are delicately laminated throughout; they make up the upper portion of the valley fillings; they are quite uniform in character and composition both laterally and vertically; they are unusual chemically, especially in the content of potash; they maintain for their upper limit a rather constant elevation around 800 feet; they are present in such volume as to have required considerable time for deposition; they possess a marked but somewhat false plasticity and during deposition they were little contaminated by materials from the adjacent uplands.

From a consideration of these features several conclusions regarding the origin of the silts may be reached:

1. The Minford silts were deposited in rather deep and comparatively quiet waters which were ponded to lakelike conditions throughout the troughs of the old preglacial streams. The waters had slight motion and stood well towards the rims of the basins.

2. The flooded condition must have been of considerable duration to account for the deposition of so much fine material. These silts are of a specialized character that shows them to have been slowly laid down.

3. The flooding was sufficient to pour the waters over low divides and thus inaugurate a new system of drainage far different in pattern from the old.

Origin of Present Drainage

The evidence is rather conclusive that the recession of the waters in these flooded valleys took place gradually and was effected only through the action of the new-born streams as they slowly cut their channels through the rock divides. Thus these ponded waters were simply drained away in a quiet fashion. Assuredly somewhere north of the present glacial boundary, the lower courses of the old north-flowing master streams were permanently dammed by a barrier either of glacial origin or due to an upwarping of the strata. This obstructing was so thorough and effective that the original drainage systems were never restored. Such a shifting of the drainage had other modifying effects. As the new streams had lower outlets and thus higher gradients than the old, the rejuvenation resulting therefrom caused the more youthful channels to be eroded from 200 to 250 feet deeper than the former beds. This increased activity was

effective also in a rather thorough removal of most of the cols and constrictions, in a widening of the new waterways to ample proportions and often in nearly complete obliteration of parts of the old beds.

The amount of work accomplished by the new streams is large, requiring a considerable duration of time. South of the terminal moraine, that is, between Chillicothe and the Ohio River, the outwash of neither the Illinoian nor the Wisconsin drift reached the level of these old valley floors. No glacial material is superimposed on or mixed with these silt and sand fillings. The new system of drainage was not only well developed but its floors were cut to the lowest level at the advent of the Illinoian ice invasion. Apparently all these glaciers did was to fill the new valleys with 80 to 120 feet of sand and gravel, which did not fill them to the level of the original floor. By comparing the amount of work done since these ice invasions to the amount required to carve the new system of drainage, the conclusion is forced upon one that such changes were inaugurated long before Illinoian time. The leaching of these fine-grained, compact silts to many feet in depth, the erosion of the valleys themselves and the lowering of adjacent highlands also indicate great age. Some far earlier ice invasion, such as the Kansan, would be a more probable agency.

Just what caused the ponding of the waters in this old drainage system is not clear. Little evidence is present to support a warping of the bed rock to the north. An upward movement of more than 200 feet would have been required. It is known that no fold of this kind is now present in the bed rock, for the strata have been carefully surveyed both for geological purposes and for the locating of oil accumulations. Such an upwarping would have shown also in surface features such as terraces. If the gradients of the old floors within the drift-covered area were known, the data, of course, would settle conclusively the question of warping, but as yet the details regarding these old streams are quite meager. The evidence, such as it is, indicates only a gradual, uniform fall for the stream floor to the north. The deflections of the new streams are too diversified to suggest a tilting in any given direction. If there was any appreciable crustal movement it appears to have been uniform and regional and not irregular and local.

These old streams, such as the Teays, appear to have been ponded simply by the obstructing of their lower courses. The most evident cause is an early drift sheet, one far older than Illinoian, possibly Kansan or pre-Kansan, remnants of which are found in northwestern Pennsylvania. Across northern Ohio little is known regarding the movement and the

extent of this early ice invasion, as the later Illinoian and Wisconsin sheets have obliterated the evidence of the older glacier. Its projection from Pennsylvania westward across northern Ohio would suit the conditions observed very well, as the barrier was located evidently much north of the present terminal moraine. The source of these fine-grained, highly laminated silts of Minford type is of much interest. The question that confronts one is whether they are derived from the average rocks of the basin, are of glacial origin, or are from some local special field.

Source of Materials

In any case, these silts represent only the finest products of rock reduction and were deposited in quiet waters. The material is not an ordinary alluvium or shale sediment derived from the decay of the average rocks of the basin. In the manner of deposition it is also far different from the average alluvium. The greater part of the old Teays drainage basin lies in the Permian, Pennsylvanian, or Mississippian systems, the abundant rocks of which are sandstones and shale. Along with these some clay, limestone, coal and iron ore are also present. The weathered and water-sorted products from such strata are more siliceous and more claylike than are these old Minford silts. No alluviums of present origin along the Ohio are of this character.

The fine materials direct from glacial action are rock flours with a wide range of minerals, both primary and secondary. Even after much weathering of the glacial debris and under extreme separation by means of moving water, the resulting silt is very different from that found in these old abandoned valleys. The nearest approach is the glacial lake clays found within the drift border. In the main the evidence is not favorable for glacial origin of the Minford silt.

The high content of micaceous minerals in the Minford silts rather definitely assigns the origin to some schist area. The only rocks of this character that were possibly available for such sediments were those of the Piedmont plateau of Virginia and adjacent areas. During Parker time the erosive forces were able to extend streams across the Appalachian Mountains and head them well out in the Piedmont. Such an extension is supported by other evidence aside from the silts, such as the size of the valleys of the master streams, the low gradient of the bed rock and the migration of plant life from south to north along these courses. During the ponded stage most of the sediments would be obtained from the headwater areas, as the lower portions of the basins were too deeply

flooded for active erosion of the bordering lands and as the glacier, if it were the obstructing factor, would have contributed little material except near the ice border. Although the evidence is far from conclusive, it supports in the main the assumption that these fine-grained silts were gathered largely from the schists of the Piedmont plateau.

Conclusion

In conclusion, the chief events in the history of these drainage modifications appear to be that the ponding in the original river basins was caused by the invasion into northern Ohio of one of the early drift sheets; that the fine-grained, laminated silts of the Minford type were derived from schists of the Piedmont plateau; that they were laid down during this slack-water stage which was of considerable duration; that the new drainage lines were established simply by the ponded waters pouring over low cols and divides; that the new streams flowed undisturbed until they had cut youthful valleys much below the former drainage level, and that the effects of the later Illinoian and Wisconsin sheets were only to fill the new drainage ways with some 100 feet or more of outwash sand and gravel.

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CORRELATION OF MONTANA ALGONKIAN FORMATIONS*

BY C. H. CLAPP AND C. F. DEISS

(Presented before the Society December 31, 1930)

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* Published with the permission of the Director of the Montana Bureau of Mines and Geology.

Manuscript received by the Secretary of the Society January 23, 1931.

Introduction

In the summer of 1921 the Montana Bureau of Mines and Geology commenced a reconnoissance survey of western Montana, following the completion of a reconnoissance of the central and eastern part of the State. During the first summer, G. S. Lambert, Arthur Bevan, and C. H. Clapp were the geologists, and in 1923 Roy Wilson joined the survey. From 1924 to 1928 the work was carried on in an unsystematic manner by C. H. Clapp, except in the summer of 1925 when he worked with J. H. Bradley, Jr., for three weeks in the confused group of mountains near the south end of the Flathead Range where it is joined by the Lewis and Clark Range. In 1929 C. H. Clapp, accompanied by G. R. Megathlin, began a more systematic study of the Lewis Range of Glacier Park and of the Flathead, and Lewis and Clark ranges. In 1930 C. H. Clapp and C. F. Deiss carried a section across western Montana from the region near Missoula to Helena, crossing the south ends of the Mission, Swan, and Lewis and Clark ranges. C. M. Langton surveyed in detail a small area in the Lewis and Clark Range in the vicinity of Shaffer Meadow.

In 1921 there were eight well-known published stratigraphic sections of the Belt rocks: in the Belt Mountains by Walcott,[1] in the Flathead, Swan, and Mission mountains by Walcott,[2] in Glacier Park by Willis,[3] in the Cœur d'Alene mining region by Calkins,[4] in northwestern Montana by Calkins,[5] in the Philipsburg area by Calkins,[6] along the Forty-ninth Parallel in Canada, north of western Montana and Idaho by Daly,[7] and in Southeastern British Columbia by Schofield [8] (see figure 1).

In addition, P. A. Billingsley and J. A. Grimes of the Anaconda Copper Mining Company, assisted by other geologists, had mapped portions of the timberlands of the company in western Montana, and had prepared a correlation table which was never published.

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[1] C. D. Walcott: Pre-Cambrian fossiliferous formations. Bull. Geol. Soc. Am., vol. 10, 1899, pp. 203-209.

[2] C. D. Walcott: Algonkian formations of northwestern Montana. Bull. Geol. Soc. Am., vol. 17, 1906, pp. 2-7.

[3] Bailey Willis: Stratigraphy and structure, Lewis and Livingston ranges, Montana. Bull. Geol. Soc. Am., vol. 13, 1902, pp. 314-324.

[4] F. C. Calkins (with F. L. Ransome): The geology and ore deposits of the Cœur d'Alene districts, Idaho. U. S. Geol. Survey, Prof. Paper 62, 1908, p. 25.

[5] F. C. Calkins: A geological reconnoissance in northern Idaho and northwestern Montana. Bull. 384. U. S. Geol. Survey, 1909, pp. 7-91.

[6] F. C. Calkins (and W. H. Emmons): Description of the Philipsburg quadrangle, Montana. U. S. Geol. Survey Atlas, Folio 196, 1915.

[7] R. A. Daly: Geology of the North American Cordillera at the Forty-ninth parallel. Canada Geol. Survey, Mem. 38, pt. I, 1912, pp. 49-83.

[8] S. J. Schofield: The pre-Cambrian (Beltian) rocks of southeastern British Columbia and their correlation. Canada Geol. Survey, Museum Bull. 2, 1914, pp. 79-91.

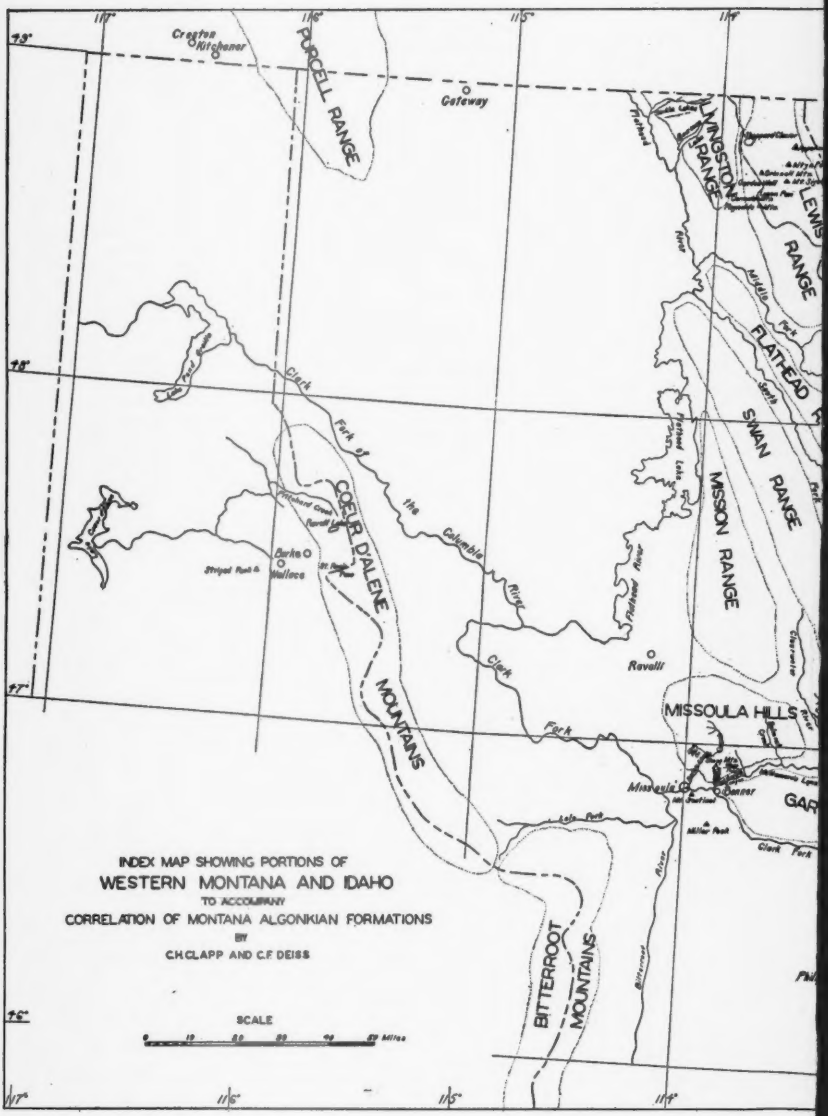


FIGURE 1.—*Index Map showing Portio*

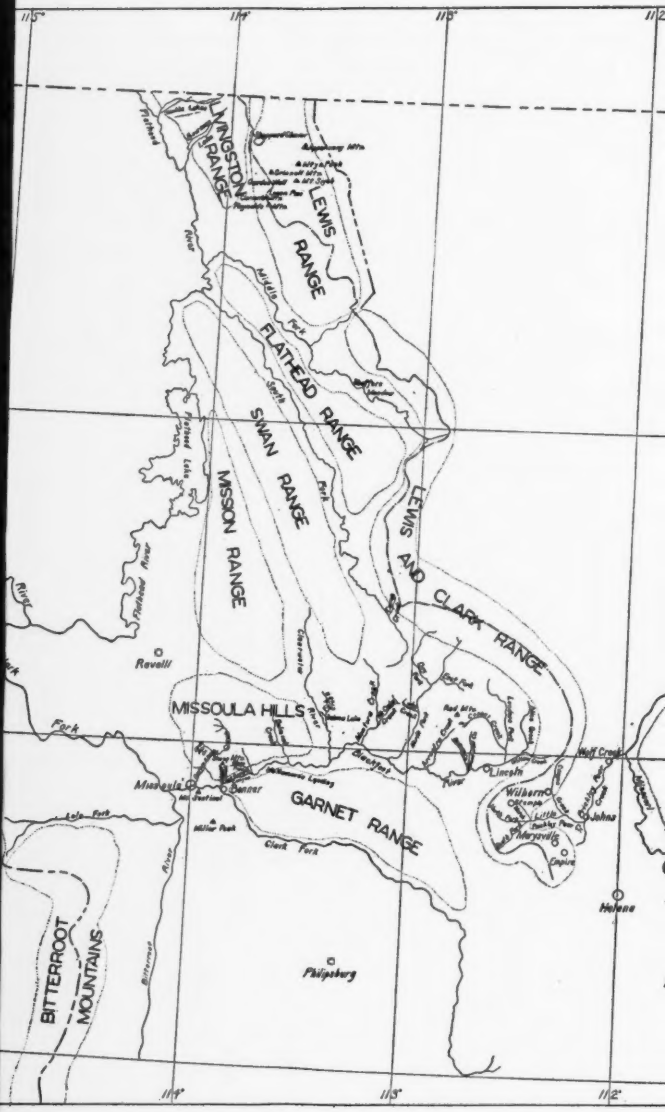
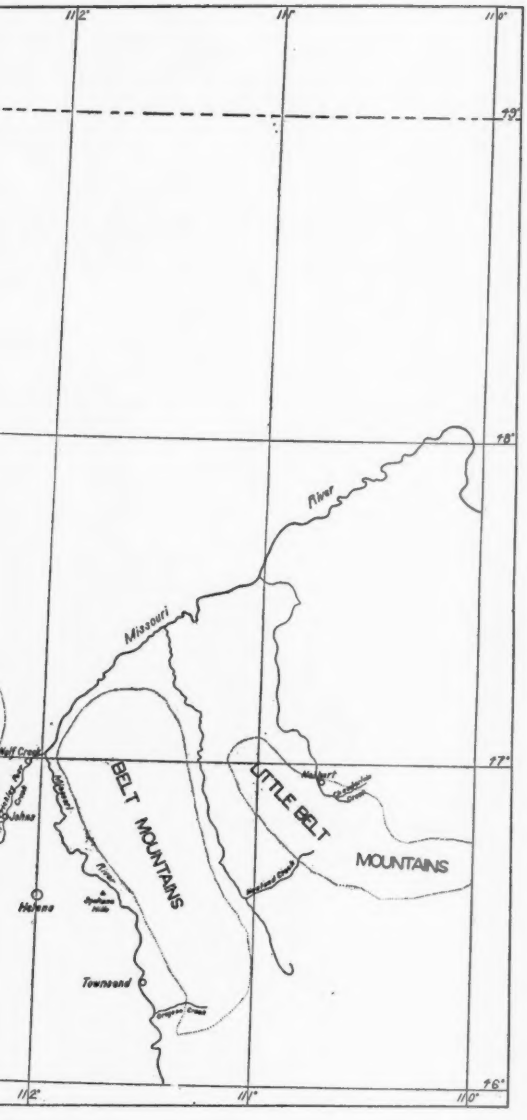


FIGURE 1.—*Index Map showing Portions of western Montana and Idaho*


112°
111°
110°
19°
18°
River
Missouri
17°
BELT MOUNTAINS
LITTLE BELT
MOUNTAINS
Helena
Townsend
16°
112°
111°
110°

ho

Although the Belt rocks were first roughly subdivided by G. M. Dawson, in 1875 [9] and 1885,[10] who assigned them to the Paleozoic, the first satisfactory subdivision was made by Walcott [11] in 1899.

In 1902 Willis [12] published the Glacier Park section, and correlated the Altyn of that section with the Newland of the Belt section, primarily on the basis of *Beltina danai* in these two formations.

In 1906, after making a reconnoissance across the Lewis and Clark, Swan, and Mission ranges, Walcott [13] published the first correlation table. In this paper he introduced two new formation names, the "Camp Creek series" and the "Blackfoot limestone," correlating the Blackfoot limestone with the Wallace of the Cœur d'Alene section and the Newland limestone of the Belt Mountains, which, following Willis, he correlated with the Altyn limestone of Glacier Park. Unfortunately, the part of the Blackfoot limestone which appeared to Walcott to underlie the Camp Creek series is a down-faulted block of Paleozoic limestone, although the section which he measured along the North Fork of the Blackfoot River below Dry Fork is in the Belt series.

During the time that Walcott was working in the Belt rocks of Montana, Calkins [14] was working in the Cœur d'Alene district, and in Philipsburg, publishing his reports and maps of the districts in 1908 and 1915 respectively. He also made a general reconnoissance in northern Idaho and northwestern Montana.[15]

Calkins' Philipsburg section in which the Belt rocks were divided into the Neihart, Pritchard, Ravalli, Newland, and Spokane formations has been accepted for general use for all the geological mapping in western Montana since 1915, and was used by the geologists of the Anaconda Copper Mining Company and by those of the Montana Bureau of Mines and Geology.

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[9] G. M. Dawson: Report on the geology and resources of the region in the vicinity of the Forty-ninth Parallel from the Lake of the Woods to the Rocky Mountains. British North American Boundary Commission, Montreal, 1875.

[10] G. M. Dawson (and R. G. McConnell): Report on the region in the vicinity of the Bow and Belly rivers, Northwest Territory. Canada Geol. Survey, Rep. of Progress, 1882-1884. 1885.

[11] C. D. Walcott: Pre-Cambrian fossiliferous formations. Bull. Geol. Soc., Am., vol. 10, 1899, pp. 201-208.

[12] Bailey Willis: Op. cit., pp. 316-317.

[13] C. D. Walcott: Algonkian formation of northwestern Montana. Bull. Geol. Soc. Am., vol. 17, 1906, p. 18.

[14] F. C. Calkins: Op. cit.

[15] F. C. Calkins: A Geological reconnoissance in northern Idaho and northwestern Montana. Bull. 384, U. S. Geol. Survey, 1909.

Meanwhile Daly [16] had published the Forty-ninth Parallel section, in which he correlated the rocks in Glacier Park and of the Forty-ninth Parallel with the previously published sections. Daly's sections were more carefully measured and amplified by Schofield,[17] who worked for many years in southeastern British Columbia. Schofield's contribution was the recognition of the unconformity between the Belt series and the overlying Cambrian rocks in Canada.

In 1924 Wilson [18] presented a tentative correlation as a result of the work of Clapp, Wilson, Lambert, and Bevan which followed the classification previously made by Walcott and Calkins, in which the Helena limestone of the Belt section was correlated with the Siyeh limestone of Glacier Park, the Newland limestone of the Belt section with the Wallace limestone of the Cœur d'Alene section and with the Altyn limestone of Glacier Park. This correlation, especially that of the Wallace with the Altyn and the Camp Creek with the Spokane was questioned by Sampson,[19] who had worked in the Pend Oreille region of Idaho. Sampson presented his correlation to the Geological Society of America in 1926, but has not yet published it. In general he correlated the Wallace with the Blackfoot, Siyeh, and Helena, and the Pritchard with the Altyn and the Newland.

Clapp was convinced in the summer of 1929 that the Wallace and the Siyeh were properly correlated with each other, as well as with the thick limestones of the western portion of the mountain areas of Montana, which had previously been called Blackfoot or Newland.

Obviously the difficulty in the correlation that has been experienced by all workers in this area was the acceptance of the correlation proposed by both Walcott [20] and Calkins,[21] that the thick limestones of the western ranges of Montana were to be correlated with the Newland of the original Belt section. Because of this fact, the writers during the summer of 1930 made a careful stratagraphic section of the rocks near Missoula, and traced and mapped the formations from Missoula to Helena. The results of this work revealed that all previous correlations were partly correct, but fail

[16] R. A. Daly: Op. cit., p. 49.

[17] S. J. Schofield: Relationship of the Precambrian (Beltian) Terrain to the Lower Cambrian strata of southeastern British Columbia. Bull. 35, Canada Dept. Mines, Geol. Series, No. 42, 1922, pp. 3-15.

[18] R. A. Wilson, J. S. Lambert and C. H. Clapp: Belt series in Montana. Bull. Geol. Soc. Am., vol. 35, 1924, abstract, pp. 91-92.

[19] Edward Sampson: Belt sedimentation and correlation. Bull. Geol. Soc. Am., vol. 38, 1927, abstract, p. 111.

[20] C. D. Walcott: Op. cit.

[21] F. C. Calkins: Description of the Philipsburg Quadrangle, Montana. U. S. Geol. Survey Atlas, Folio 196, 1915.

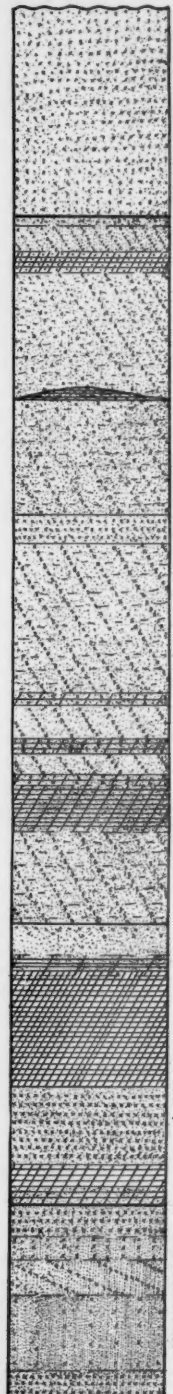

FIGURE 2.—*Stratigraphic*

...est Canyon Sections *Scale 1:12000*

Clapp and Davis

...e, red to pink-white, cross bedded, purple-banded, pure
...ite. Mud-ball conglomerate in upper and lower portions
...mation. Maroon to gray-white weathering.

...green-brown, and red-gray, micaceous, sandy, thin-
... quartzite. Occasional bands of sandy argillite.
...brown weathering.

...blue-gray, finely crystalline limestone, interbedded
...rregular bands of calcareous shale.

...e, pure, coarse-grained, pink-white, cross bedded,
...ous, purple-banded quartzite. Dull red to buff weathering.

...to green-gray, sandy, micaceous quartzite.
...brown weathering.

...to green-gray, argillitic, micaceous sandstone and
...quartzite. Rusty-brown weathering.

...lack to dark blue-gray, sandy, micaceous argillite.
...brown weathering.

...edded, siliceous, micaceous, brown, green-gray and gray,
...-grained quartzite. Buff to rusty-brown weathering.

...itic sandstone, and thin beds of sandy quartzite near top.
...o buff weathering.

... green and red, very fine-grained, mud-cracked and ripple-
... argillite. Gray and dull lavender weathering.

...e, pink-white, pure, coarse to fine-grained quartzite.
...bedded, and occasionally ripple-marked. Sandy near top.
...eathering.

...reen-gray and purple, micaceous, sandy argillite. Some
...edded, massive quartzite. Lavender to buff weathering.

...e, thick bedded, coarse-grained, banded quartzite.
...ted buff, gray and lavender weathering.
... bedded, red-gray, finely banded and ripple-marked
...ite. Lavender weathering.

...e, pink-gray, quartzitic sandstone. Buff weathering.

...e, fine-grained, siliceous, gray quartzite.
...eathering
...e to thin bedded, argillitic sandstone.
...vender weathering.

...urple and gray-green, sandy, mud-cracked and ripple-
... argillite. Some interbedded argillitic sandstone,
...e fine-grained, purple-gray argillite.
...rple weathering.

...itic, fine-grained sandstone. Dull red-purple weathering.

...d-purple, sandy argillite with some siliceous, sandy,
...e to thin bedded, purple argillite. Mud-cracked in
... Dull lavender weathering.

...atigraphic Section of Missoula Group

to recognize that the argillites and the quartzites separating the Helena and Newland limestones in the Belt Mountains thin to the northwest and west to such an extent that the workers in the western ranges had mapped these limestones as a single formation.

Missoula Group

GENERAL STATEMENT

Inasmuch as the limestones of the western ranges in the vicinity of Missoula had been correlated with the Newland of the Belt Mountains, the careful measurement of the thick series of argillites and quartzites which overlie these limestones in western Montana, and the comparison of these clastics with the rocks which overlie the Newland of the Belt section was of utmost importance. The results were surprising in that more than 18,000 feet of rocks lying above the Wallace limestone were measured in the vicinity of Missoula.

GEOGRAPHIC POSITION

The thickest exposures of the Missoula group of rocks lie in the mountains to the east of the city of Missoula. These rocks are specially well exposed on the hillsides to the east and west of Rattlesnake Creek, northeast of Missoula, on the southern flank of Miller Peak, southeast of Missoula, and along both sides of the Blackfoot River from its mouth at the town of Bonner, eastward as far as the mouth of Belmont Creek (see figure 1).

STRATIGRAPHIC POSITION

General statement.—The base of the Missoula group is exposed on Miller Peak. The lower part of Miller Peak is composed of shaly, siliceous limestone, with occasional intercalated chert bands. These calcareous beds grade upward into a calcareous, argillaceous sandstone. Lying directly on this bed is a deep, red-purple, sandy argillite which is the basal bed of the Miller Peak formation, the bottom member of the Missoula group. The fact that the limestone forming the base of Miller Peak is traceable into the Lolo Fork area 12 miles to the west, where it lies directly on Ravalli quartzite, makes its stratigraphic position certain, and at the same time places the Missoula group in the uppermost part of the Belt terrane.

The following are the formations which comprise the Missoula group:

	Feet
Sheep Mountain	2,300
Garnet Range	7,600
McNamara	3,000
Hellgate	2,200
Miller Peak	2,900
Total	18,000

Miller Peak formation.—The lower 1,100 feet of the Miller Peak formation is composed of deep red-purple sandy argillite with some siliceous, sandy, massive to thin-bedded purple argillite. Intercallated between these beds are a few thin beds of fissile, gray, sandy, mud-cracked argillite. In places there are beds of micaceous argillite near the top of the lower set of beds. Most of the rocks of the lower 1,100 feet weather to a dull purple-lavender color, which is characteristic. Overlying the lower beds are about 1,500 feet of mixed purple and green-gray, sandy, mud-cracked, and ripple-marked argillite, interbedded with some massive beds of argillitic sandstone and an occasional thin bed of fine-grained purple-gray argillite. Of this group of rocks, the purple beds weather to a dull red-lavender color, while the green-gray beds weather to a dull gray. The upper 300 feet of the Miller Peak is dominantly a massive to thin-bedded argillitic sandstone, which becomes increasingly sandy toward the top. The following section of the Miller Peak formation was measured on Miller Peak.

	Feet
Purple massive to thin-bedded argillitic sandstone, and some gray argillite. Lavender to maroon weathering	235
Red and purple sandy argillite, with some thin beds of green and gray argillite. Occasional beds of argillitic sandstone intercallated between argillite beds	1,440
Pale green-gray argillitic sandstone	85
Purple and green-gray sandy, micaceous argillite; weathers to rusty-buff color on joint faces	590
Purple sandy thin-bedded mud-cracked siliceous argillite. Occasional beds of finely micaceous argillite and gray sandy argillite. Beds weather dull red-purple with greenish streaks	550
Total	2,900

The contact of the Miller Peak with the overlying Hellgate formation was not seen in the section on Miller Peak, but was observed on the north side of Mount Sentinel about 8 miles to the northwest of Miller Peak,

where the lowest bed of the Hellgate overlies a sandy argillite similar to that exposed at the top of the Miller Peak section. This seems to imply that the highest bed in the Miller Peak section is close to the base of the overlying Hellgate quartzite, and therefore but little of the formation is missing. The Miller Peak formation measured on Miller Peak is 2,900 feet in thickness. The type section of the Miller Peak formation is the upper portion of the southern flank of Miller Peak, extending from the contact with the Wallace (Siyeh) limestone at an elevation of 6,040 feet to the top of the peak at an elevation of 7,010 feet. The top of Miller Peak is in township 12 north, range 18 west, section 32.

Hellgate formation.—A massive red-gray coarse-grained quartzite, with sandy quartzite beds up to 3 feet in thickness, forms the lower 100 feet of the Hellgate formation. Overlying the basal quartzite are massive beds of fine-grained siliceous gray quartzite, aggregating about 300 feet in thickness. Ripple marks are common throughout these beds. Above the gray siliceous quartzite is 1,200 feet of massive pink-gray quartzitic sandstone. The upper 600 feet of the Hellgate consists of a gray-red to dull gray, massive, fine- to coarse-grained, finely banded and ripple-marked quartzite, with massive, thick-bedded quartzitic sandstones in the middle part of the strata. The upper part becomes increasingly siliceous toward the top. For the greater part, the rock of the Hellgate formation weathers to a dull red-buff or drab-lavender color, although the 300-foot stratum of gray siliceous quartzite in the lower part of the formation weathers to a buff or straw color. The total thickness of the Hellgate formation is 2,200 feet. The following section of the Hellgate formation was measured on the north side of Mount Sentinel, the southern wall of Hellgate Canyon.

	Feet
Massive gray-red siliceous quartzite. Weathers variegated gray, buff, and lavender	365
Massive gray and red-gray fine- to coarse-grained finely banded pure quartzite and sandy quartzite. Ripple marks common	280
Massive thick bedded pink-gray quartzitic sandstone. Buff weathering	1,160
Massive gray fine-grained siliceous quartzite. Ripple marks common. Buff weathering	300
Massive red-gray coarse-grained quartzite, with sandy beds up to 3 feet in thickness. Buff and dull lavender weathering	95
Total	2,200

The type section of the Hellgate formation is to be seen on the north side of Mount Sentinel, near the tracks of the Chicago, Milwaukee & St.

Paul Railway, from a point about 1¼ miles east of the railroad station at Missoula, east along Hellgate Canyon for nearly 1 mile.

McNamara formation.—The McNamara formation is divided into three members, the middle one of which is sharply distinguished lithologically from the upper and lower ones. The lower member consists of 400 feet of drab green-gray to purple and maroon-colored micaceous and sandy argillite which becomes more sandy upwards. Near the top of the lower member are interbedded massive beds of sandy quartzite which forecast the conditions during the deposition of the overlying or middle McNamara member. The lower 40 feet of the middle member of the McNamara formation is composed of massive gray-green coarse-grain sandy quartzite which is cross-bedded, ripple-marked, and cut by many quartz veinlets. The upper 800 feet of the middle member is composed of a number of massive beds of pink-white and red-gray, pure, coarse- to fine-grained quartzite, which is cross-bedded, occasionally ripple-marked, and which weathers to a dull rusty-buff color. Toward the top the quartzite becomes slightly sandy, and has several thin intercallated beds of sandy argillite. Upon weathering, the lower portion of the quartzite produces talus of large, massive blocks, whereas the upper portion of the quartzite produces talus of much smaller fragments which tend to be slightly fissile. The upper member of the McNamara formation is, for the greater part, a series of bright green and red, fine-grained, mud-cracked and ripple-marked argillite. Dense, fine-grained, chertlike green argillite is irregularly interbedded with the more massive strata. There are several horizons of "clay galls" [22] in the upper part of this formation. Toward the top of the McNamara formation, the argillite becomes sandy and quartzitic, passing into the overlying Garnet Range formation through a series of beds showing a gradual lithologic transition without any apparent break in sedimentation.

The following section of the McNamara formation was measured in the canyon of the Blackfoot River immediately east of the town of Bonner, extending for slightly more than a mile toward McNamaras Landing.

	Feet
Maroon and gray, massive, medium- to coarse-grained sandy quartzite, with several beds of sandy argillite. Mud flake conglomerate (clay galls) in one bed near top	330
Massive red and gray quartzitic argillite. Finely banded and mud-cracked in places	250

[22] W. H. Twenhofel: Treatise on sedimentation. Williams and Wilkins Company, 1926, p. 497.

	Feet
Red, green, and gray fine-grained, dense, thin-bedded argillite. Sandy beds present near top. Mud cracks common in some beds	630
Maroon, pale green, and gray fine-grained argillite. Many thin beds of very dense, chertlike green argillite. In general red beds coarser-grained than green beds	480
Gray and greenish gray argillitic thin-bedded sandstone. Gray weathering	90
Massive pink-white quartzite and gray sandy quartzite. Ripple marks common in both beds. Rock weathers to thin plates, and to a buff color	100
Massive quartzite interbedded with maroon sandy argillite	190
Massive pink-white quartzite. Forms talus slopes of small fragments	75
Massive pink-white quartzite. Forms talus slopes of large blocks. Buff weathering	300
Massive to medium-bedded, pink-gray, finely banded quartzite, with quartz veins up to 1 inch in thickness	105
Massive gray-green coarse-grained sandy quartzite. Cross-bedded, ripple-marked, and with many quartz veinlets. Buff weathering	40
Purple to green-gray micaceous sandy argillite, with thin sandy quartzite beds in the upper part. Buff weathering	410
Total	3,000

The type section of the McNamara formation is seen along the Blackfoot River in the vicinity of McNamaras Landing. Two miles north of McNamaras Landing the McNamara formation rests conformably on the underlying Hellgate formation. Further, along the north side of Mount Sentinel, the lower McNamara argillite is to be seen in direct contact on the upper Hellgate quartzite. A fault displaces the middle and upper part of the McNamara formation in the Mount Sentinel section, preventing the measurement of the formation at that place.

Garnet Range formation.—The Garnet Range is the thickest formation of the Missoula group. The lower 1,600 feet is made up of brown, green-gray to gray thin bedded siliceous, micaceous, coarse-grained quartzite, with argillitic and coarse-grained quartzitic sandstones near the base. Six hundred feet of black-gray to dark blue-gray sandy micaceous argillite overlies the lower beds. These black argillites weather to a buff fissile talus. Overlying the black argillites are 1,000 feet of brown to green-gray argillitic, micaceous sandstone and sandy quartzite, which in turn is overlain by 1,600 feet of thin-bedded brown-gray to green-gray quartzitic sandstone.

A conspicuous stratum of massive coarse-grain pink-white cross-bedded pure siliceous quartzite of about 300 feet in thickness divides the Garnet Range formation into an upper and a lower part. The upper 3,050 feet of the Garnet Range formation is composed of beds of brown, green-brown, and red-gray-brown micaceous and sandy thin-bedded and occasionally argillitic quartzite.

At the head of Lime Kiln Creek, a tributary of Rattlesnake Creek, there is a lens of limestone composed of blue-gray finely crystalline calcite with irregular bands of calcareous salmon-colored shale. The middle beds of the lens are cut with calcite veins and concretions. One bed in the central part of the lens is distinctly oolitic. The pure limestone weathers to a pale gray color, and the irregular shaly bands weather bright buff. The measured thickness of this limestone is 110 feet. The lenticular character is inferred from the fact that the limestone does not occur in any other known section of the Garnet Range formation. The top of the lens lies about 1,800 feet below the top of the formation.

The following section of the Garnet Range formation was measured on the north side of the Blackfoot Canyon from Johnson Gulch eastward to 1 mile below the mouth of West Twin Creek.

	Feet
Massive gray and buff sandy quartzite. Finely banded	90
Coarse-grained cross-bedded ripple-marked and banded sandy, siliceous quartzite. Some beds of maroon sandy, micaceous argillite	170
Massive purple-red sandy argillitic quartzite, and occasional beds of cross-bedded quartzitic sandstone. Rusty-brown weathering	350
Green, gray, and mottled brown micaceous, sandy thin-bedded quartzite. Rusty-brown weathering	720
Green-brown and gray-brown sandy, micaceous quartzite. Some beds finely banded. Lower beds cut by quartz veins. Rock massive, weathering to thin beds. All beds weather rusty-brown	1,770
Massive pink-white cross-bedded purple-banded pure quartzite. Buff weathering	330
Thin-bedded brown-gray to green coarse-grained micaceous quartzite. Weathers red, gray, and brown	1,410
Brown and dull red to green fissile micaceous, sandy, siliceous argillite. Some interbedded gray-green sandy quartzite. Red-brown weathering	580
Gray-green-brown siliceous flaggy quartzite. Buff weathering	250
Black to dark blue-gray micaceous, sandy argillite, and fine-grained argillitic sandstone. Brown-buff weathering	560
Green-gray and brown sandy, siliceous quartzite. Massive to thin-bedded. Micaceous, sandy quartzite in lower part. All beds rusty-brown weathering	850

	Feet
Quartzitic sandstone and gray micaceous coarse-grained sandy quartzite. Gray-buff weathering	310
Massive to thin-bedded argillitic, quartzitic, micaceous sandstone. Lower part of sandy argillite, with thin beds of sandy quartzite. Gray weathering	210
Total	7,600

The type locality of the Garnet Range formation is the north side of the Blackfoot Canyon from Johnson Gulch, 2 miles east of Bonner, eastward to 1 mile from the mouth of West Twin Creek. The Blackfoot Canyon forms the northwest boundary of the Garnet Range, the western part of which is composed largely of the rocks of the Garnet Range formation.

Sheep Mountain formation.—The uppermost formation of the Missoula group, called the Sheep Mountain, is composed of massive beds of red to pink-white coarse-grain cross-bedded purple-banded pure quartzite. The upper and lower portions of the formation are characterized by the presence of several beds of clay galls.

The following section of the Sheep Mountain formation was measured on the upper slopes of Sheep Mountain.

	Feet
Massive red, and some white quartzite. Beds of clay galls near top. Deep red weathering	1,050
Massive pink-white coarse-grained cross-bedded quartzite, with some beds of coarse-grained sandstone in the upper part. All beds weather gray-red	695
Massive pink and white coarse-grained cross-bedded quartzite. Numerous bands of clay galls near base. Red-gray weathering	555
Total	2,300

The type locality of the Sheep Mountain formation is the upper 1,000 feet of Sheep Mountain, which lies in township 15 north, range 18 west, section 24, and in township 14 north, range 17 west, section 30. In the type locality the Sheep Mountain formation lies conformably on the Garnet Range formation.

Continuity of Formations

Belmont Creek to Salmon Lake

The Siyeh limestone comprises the country rock from the mouth of Belmont Creek eastward along the north bank of the Blackfoot River for a distance of about 1 mile. In this region the Siveh is composed of fine-

grained, sandy red and green-gray argillite and calcareous argillite, interbedded with thin bands of green-gray pure crystalline limestone. Ripple marks and small mud cracks are common in these strata. Both the argillite and the limestone weather to a pale buff color. The present interpretation of the stratigraphic position of these beds is that they represent the transistion facie from the pure Upper Siyeh limestone into the red and green argillite of the Miller Peak formation.

The Miller Peak argillite lies conformably upon the Siyeh limestone and argillite about 1 mile northeast of the mouth of Belmont Creek, and extends east to Clearwater River. The Miller Peak argillite is lithologically normal in this area, being a red-purple to occasionally green-gray sandy argillite interbedded with much argillitic sandstone, becoming more sandy toward the top.

About one-eighth of a mile south of the mouth of the canyon of Lost Horse Creek, a tributary of Clearwater River, the Hellgate quartzite is in normal contact with the Miller Peak argillite.

To the north, the hills west of the southern part of Salmon Lake are composed of Siyeh limestone. Here the Siyeh has been upthrown against the Hellgate by a reverse fault which trends northwest. In this area the Siyeh is a massive dolomitic and siliceous, argillaceous limestone, with but few argillite bands.

In the gulch east of the narrowest portion of Salmon Lake, the upper part of the Lower Siyeh is in normal contact with red-purple sandy argillite and argillitic sandy quartzite, which weathers lavender and maroon. These rocks, the so called "red band in the Siyeh," are now correlated with the Spokane formation of the Belt Mountains. The red beds continue northward for approximately half a mile on both sides of Salmon Lake, where they are overlain conformably by the Upper Siyeh limestone. The contact is not sharp, owing to the fact that the red rocks pass upward into the Siyeh limestone through a transition series of limy, sandy argillite, to calcareous shale, to argillaceous limestone which terminates near the top of the formation in massive beds of dolomite and pure limestone. Beyond Fish Creek, which enters Salmon Lake from the northeast, the Upper Siyeh limestone is in normal contact with the overlying Miller Peak argillite.

The evidence offered by this section indicates that the red beds in the Siyeh can not be correlated with the Miller Peak argillite, a fact which becomes of paramount importance in the problem of the correlation of the eastern and western sections of the Belt rocks.

The Miller Peak and Hellgate formations can be traced east, from Clearwater River up the Blackfoot River. Six miles east of Clearwater River, the Lower Siyeh is upthrown against the Hellgate by a continuation of the fault at Salmon Lake.

MONTURE CREEK TO NORTH FORK OF BLACKFOOT RIVER

One of the best sections for the illustration of the sequence and relationships of the Lower Siyeh, red beds in the Siyeh, Upper Siyeh, Miller Peak, and Hellgate formations is disclosed in McCabe Creek and Lake Creek valleys between Monture Creek and the North Fork of Blackfoot River.

The Lower Siyeh limestone is intermittently exposed on the hills to the north of McCabe Creek from the mouth of McCabe Creek Canyon eastward for about 1.2 miles. At this point the Lower Siyeh is interrupted by a sill of gabbro-diorite which has contact-metamorphosed the continuous limestone. The Lower Siyeh continues northeastward for about 1.5 miles, at which point it is overlain in normal contact by red argillite and argillitic sandstone. These argillite and sandstone beds become dominantly green and mixed green and red upward, and are in turn overlain, again in normal contact, by Upper Siyeh limestone. Here as elsewhere in the western sections of the Siyeh, the Upper limestone is much less shaly and is purer than that beneath the red argillite.

In the hills three-quarters of a mile to the north of the Lake Creek Trail and about 1.2 miles east of the divide beween Lake and McCabe Creeks, the Miller Peak argillite lies conformably upon the Upper Siyeh limestone. In this same area the Miller Peak is overlain by the Hellgate quartzite.

A north-south fault near the mouth of Lake Creek displaces the Miller Peak and Hellgate formations so that in the canyon of the North Fork of Blackfoot River the Lower Siyeh limestone is exposed a second time in this section.

NORTH FORK OF BLACKFOOT RIVER TO EAST FORK

The lowest formation in the section along the North Fork of Blackfoot River is the Appekunny quartzite, which is exposed in the sides of the valley, which the canyon widens as the river flows into Kleinschmidt flat. The Appekunny is separated from the overlying Grinnell argillite by a gabbro-diorite sill. The Lower Siyeh limestone lies conformably upon the Grinnell at a point about 1.7 miles north of the mouth of the canyon, and continues up the canyon for approximately 4 miles. Here it is overlain

conformably by purple-red and green argillite and quartzite, which continues up the canyon for slightly more than a mile. Above the red and green argillite and quartzite, the Upper Siyeh (Blackfoot) limestone is exposed as far north as the Dry Fork of the North Fork of Blackfoot River. Here the Miller Peak argillite (Lower Camp Creek series of Walcott[23]) lies conformably upon the Upper Siyeh limestone and continues northward to the East Fork of the North Fork of Blackfoot River.

The argillite and quartzite between the Upper and Lower Siyeh limestones is the same red band which occurs at the same stratigraphic horizon in the Salmon Lake and McCabe Creek-Lake sections. This argillite and quartzite is, however, thicker in this section.

The Lower Siyeh and the superjacent red and green argillite and quartzite are traced eastward to Arrastre Creek, which is the next section given.

ARRASTRE CREEK

Near the mouth of Arrastre Creek Canyon on the western side, the Appekunny quartzite outcrops and forms the lower three-quarters of a mile of the canyon sides. The top beds of the Appekunny are separated by a gabbro-diorite sill which is a continuation of the sill exposed near the mouth of the Blackfoot Canyon. Above this sill the Grinnell argillite forms the rocks of the next mile. Although the contact is covered by a thick mantle of glacial drift, the Lower Siyeh limestone lies with apparent conformity upon the Grinnell argillite and shows poor exposures for about 2 miles up the canyon. At the end of this distance the Lower Siyeh limestone is overlain conformably by red-purple sandy argillite and argillitic quartzite. The Upper Siyeh limestone was not seen in this section.

The Grinnell and Lower Siyeh are traced from Arrastre Creek to Beaver Creek and thence eastward to Stonewall Creek.

STONEWALL CREEK TO RED MOUNTAIN *

The lowest formation exposed in Stonewall Creek Canyon is the Appekunny quartzite which forms the mouth of the canyon and extends northward for about one quarter of a mile, where the sequence of beds is inter-

[23] C. D. Walcott: Algonkian formations of northwestern Montana. Bull. Geol. Soc. Am., vol. 17, 1906, pp. 3-5.

* Detailed work during the summer of 1931 has shown that the Stonewall Creek to Red Mountain section is incorrect. The proper sequence of formations in this section from base to top is: a relatively narrow diorite stock, Spokane argillite and quartzite, Helena limestone, and Miller Peak argillite. The error in the Stonewall Creek to Red Mountain section, however, does not affect the correlation of the Algonkian rocks in northwestern Montana.

rupted by apparently the same gabbro-diorite sill which occurs near the top of the Appekunny in the last two mentioned sections. The remainder of Stonewall Canyon and the divide separating Stonewall Creek from Copper Lake is Grinnel argillite.

About one-half mile northeast of Copper Lake, the Lower Siyeh limestone lies in normal contact upon the Grinnell argillite. The Siyeh is exposed continuously northward for 2 miles to the southern slopes of the upper third of Red Mountain where it is overlain conformably by red-purple argillite and quartzite. This is the "red band in the Siyeh," which is again thicker here than in the canyon of the North Fork of Blackfoot River, as in that section it is thicker than in the sections to the west.

From Stonewall Creek the Lower Siyeh limestone and the red band of argillites and quartzites are traced down Copper Creek and eastward across Landers Fork of the Blackfoot River to Alice Creek.

ALICE CREEK

The strike of the Lower Siyeh swings to the south between Copper Lake and Landers Fork, causing the Lower Siyeh limestone to appear along the main Lincoln-Helena highway over an area from 1 mile west of Landers Fork eastward for about 3 miles, where the red-purple argillite and sandy quartzite overlies it in normal contact. For this reason the lowest formation in the Alice Creek section is the red-purple argillite and quartzite.

These red-purple beds have become increasingly thicker eastward from the Stonewall Creek-Red Mountain section, and, as has already been pointed out, these red beds are much thicker in the Red Mountain region than they are farther west.

In the Alice Creek section these red beds extend from the mouth of the creek northward to 1 mile north of the Alice Creek Ranger Station, where they are overlain by the Upper Siyeh limestone in normal contact. This is an important key section in the correlation of the eastern and western Belt formations because of two salient facts which it discloses: First, the Siyeh limestone of western Montana becomes two distinct formations in the eastern area of the Belt terrane; and second, the so called "red band in the Siyeh" of the western sections becomes vastly more important in the central and eastern areas.

The red argillite and quartzite between the Upper and Lower Siyeh limestones can be traced southeast to the Marysville Mining District, via Wilborn, Stemple, Marsh Creek, and the North and South Forks of Little Prickly Pear Creek.

CONTINENTAL DIVIDE TO MARYSVILLE

The lowest bed exposed in this section is the red and green argillite and quartzite of the Middle Siyeh. These rocks are exposed from Alice Creek eastward to near the continental divide at the head of Willow Creek, where they are cut by a quartz-monzonite stock of about 1 mile in width. At the head of Canyon Creek, on the east of the divide, these same red-purple and green argillites comprise the bulk of the hills into which Canyon Creek has cut its valley, although the tops of the hills are capped with Tertiary andesite. The red and green argillites and quartzites are exposed on both sides of the main highway down Canyon Creek, through Wilborn and southeastward beyond the junction of Canyon Creek and Little Prickly Pear Creek.

However, the junction of these two creeks lies within the area of the Marysville Mining District which was studied by Barrell[24] in 1901. Barrell identified and mapped these red beds as the Spokane formation, and there is no doubt concerning the accuracy of his work. The Spokane argillites extend along the north side of Little Prickly Pear Flat from the mouth of Canyon Creek, westward to three-tenths of a mile west of the mouth of Marsh Creek, where they are overlain conformably by the Empire shale of Walcott.[25] After seeing all the localities listed by Walcott in which the Empire rocks are exposed, and in addition several other localities, it is believed by the authors that the Empire formation represents a transitional phase of the Upper Spokane into the lower part of the Helena (Upper Siyeh) limestone.

The Empire formation is exposed for about 400 yards to the westward at which point it is overlain conformably by typical Upper Siyeh (Helena) limestone. This limestone outcrops intermittently on the hills to the north of Little Prickly Pear Creek, westward for about 2 miles, just to the east of the mouth of the South Fork of Little Prickly Pear Creek. At this point the limestone is in normal contact with the overlying Miller Peak argillite, which in this area is the Marsh shale of Walcott.[26] The Miller Peak (Marsh) argillite is exposed for about 1 mile up the South Fork of Little Prickly Pear Creek, where it is overlain conformably by the Hellgate quartzite. See Correlation Table, figure 3.

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[24] Joseph Barrell: Geology of the Marysville Mining District, Montana. U. S. Geol. Survey, Prof. Paper 57, 1907, pp. 8, 9, pl. I.

[25] C. D. Walcott: Pre-Cambrian fossiliferous formations. Bull. Geol. Soc. Am., vol. 10, 1899, p. 207.

[26] C. D. Walcott: Op. cit., pp. 207, 208.

Correlation of Sections

METHOD OF ATTACKING THE PROBLEM

The work of Walcott,[27] Willis,[28] and others had demonstrated that there is but a meager fauna and flora preserved in the Algonkian rocks of Montana, and with the exception of one form, *Cryptozoon*, the few organisms represented are restricted to small and widely separated areas, a fact which has been amply substantiated by all the field work on the Belt rocks. The poor state of preservation of the Belt fossils and the resultant difficulties of their accurate identification was the final factor which forced the writers to reject fossils as a basis for correlation, and to turn to other criteria.

CRITERIA USED AS BASIS FOR CORRELATION

We have used the following criteria as the basis of correlation of the Belt rocks in Montana: First, the detailed lithologic character of each formation; second, the comparison of the sequence of formations in the different stratigraphic sections; third, and most dependable and important, and the one which revealed the actual relationships of the formations in different parts of Montana, the continuity of the deposits. See pages 683 to 688.

To the south of a direct line from Missoula to Helena, the Belt rocks are complexly folded and faulted, metamorphosed and replaced by large areas of granitic rocks, and covered in places by Paleozoic and Mesozoic sediments, and Cretaceous and Tertiary volcanic rocks. Hence the area north of this line, where the structures are relatively simple, was chosen as the area through which the Belt rocks were traced from Missoula to Helena.

Because of its priority and especially because of its wide dissemination in the literature of geology, we have used the original stratigraphic section of Walcott [29] in the Belt Mountains as the type section of the Algonkian rocks in Montana. This section is unfortunate in several respects, of which the two more important are: First, the widely separated areas in which the individual formations are exposed; and second, the fact that the type localities of the formations represent only a fraction of the total thickness of the same formations in other areas. This is strikingly illustrated by the correlation table, figure 3.

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[27] C. D. Walcott: Op. cit., pp. 235-238.

[28] Bailey Willis: Stratigraphy and structure, Lewis and Livingston ranges, Montana. Bull. Geol. Soc. Am., vol. 13, 1902, pp. 317-320.

[29] C. D. Walcott: Pre-Cambrian fossiliferous formations. Bull. Geol. Soc. Am., vol. 10, 1899, pp. 203-209.

In 1906 Walcott [30] stated: "The most easterly section, that of the Belt Mountains, has more limestone in proportion to the arenaceous matter, and with the exception of the Neihart sandstone (quartzite) at the base, finer sediments; these conditions indicate that the sediments were derived mainly from a somewhat distant source of supply." The conditions he thus described are not in keeping with the evidence found by a more detailed work in the field. In fact the Helena and Newland (Upper and Lower Siyeh) limestones are much thicker in the region of the North Fork of the Blackfoot River and northwestward into Glacier Park than in the Belt Mountains. Further, the Greyson, Spokane, and Marsh are much thicker than Walcott estimated and are more arenaceous than the equivalent formations in the central and western parts of the Belt terrane. The most cogent evidence in opposition to Walcott's concept of "a somewhat distant source of supply" is the actual Archean mass upon which the Neihart quartzite lies, and the conglomerate, which Walcott [31] himself figured, at the base of the Greyson formation.

MISSOULA FORMATIONS ABOVE THE MILLER PEAK ARGILLITE

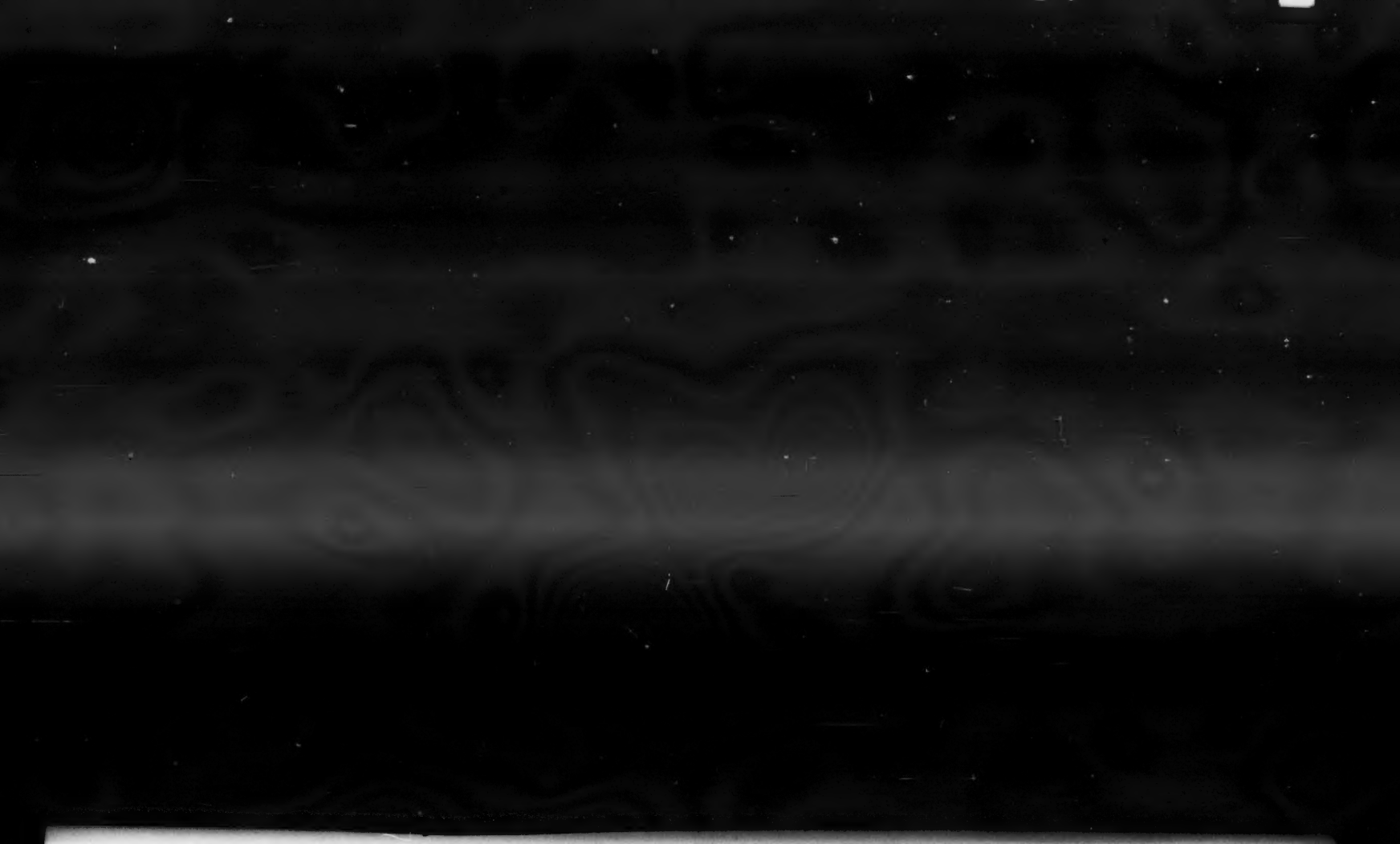
Stratigraphically, the highest Algonkian rocks in Montana are exposed in the region northeast and southeast of the city of Missoula. In this area 18,000 feet of argillites and quartzites overlie the Wallace (Upper Siyeh) limestone. Of this great thickness of Upper Belt rocks, only the lower part of the lowest formation, the Miller Peak argillite, is represented in the Belt Mountains section. The formations above the Miller Peak in the Missoula section are only partially represented in the sections of Prickly Pear Creek, McCabe Creek, Glacier Park (of Clapp), and Mission Range (of Wilson), by the Hellgate quartzite in the first two sections and by the upper 4,700 and 8,100 feet of the Missoula group in the last two sections. The rocks of the Missoula group above the Miller Peak argillite are not represented in any other sections except those referred to above.

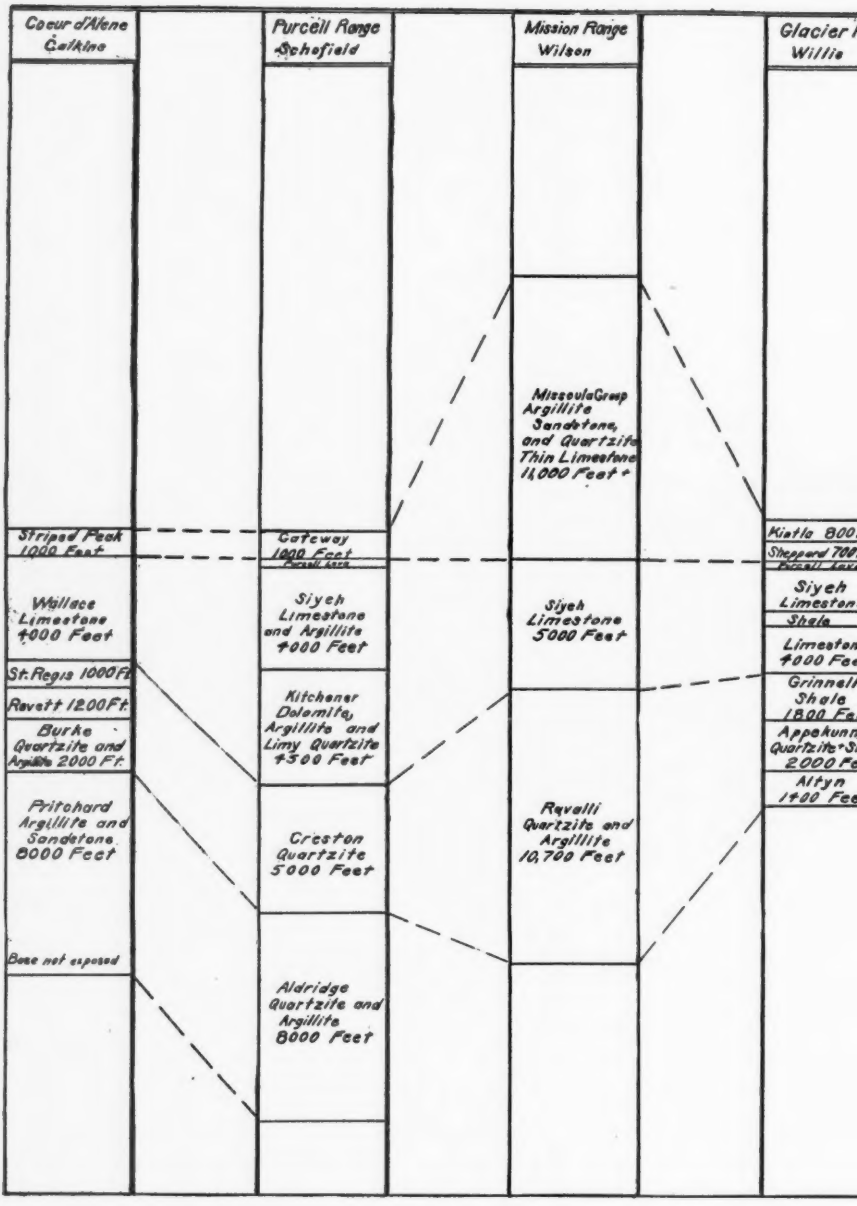
MARSH SHALE AND ITS EQUIVALENTS

The formations correlated with Marsh shale of the type section are the Miller Peak argillite in the Prickly Pear Creek, canyon of the North Fork of Blackfoot River, McCabe Creek, Salmon Lake, and Missoula sections. The Miller Peak in all but one of these sections, the Missoula, is about 1,400 feet in thickness. In the Missoula section, this formation

[30] C. D. Walcott: Algonkian formations of northwestern Montana. Bull. Geol. Soc. Am., vol. 17, 1906, p. 17.

[31] C. D. Walcott: Op. cit., plate 8.




Coeur d'Alene
Calkins
Purcell Range
Schofield
Mission Range
Wilson
Glacier
Willis
Missoula Group
Argillite
Sandstone,
and Quartzite
Thin Limestone
11,000 Feet +
Striped Peak
1000 Feet
Gateway
1000 Feet
Purcell Lava
Kintla 800
Sheppard 700
Purcell Lava
Wallace
Limestone
4000 Feet
Siyeh
Limestone
and Argillite
4000 Feet
Siyeh
Limestone
5000 Feet
Siyeh
Limeston
Shale
Limeston
4000 Fe
St. Regis 1000 Ft.
Revett 1200 Ft.
Burke
Quartzite and
Argillite 2000 Ft.
Kitchener
Dolomite,
Argillite and
Limy Quartzite
4500 Feet
Grinnell
Shale
1800 Fe
Appekunn
Quartzite+S
2000 Fe
Pritchard
Argillite and
Sandstone
8000 Feet
Creston
Quartzite
5000 Feet
Ravalli
Quartzite and
Argillite
10,700 Feet
Altyn
1400 Fee
Base not exposed
Aldridge
Quartzite and
Argillite
8000 Feet

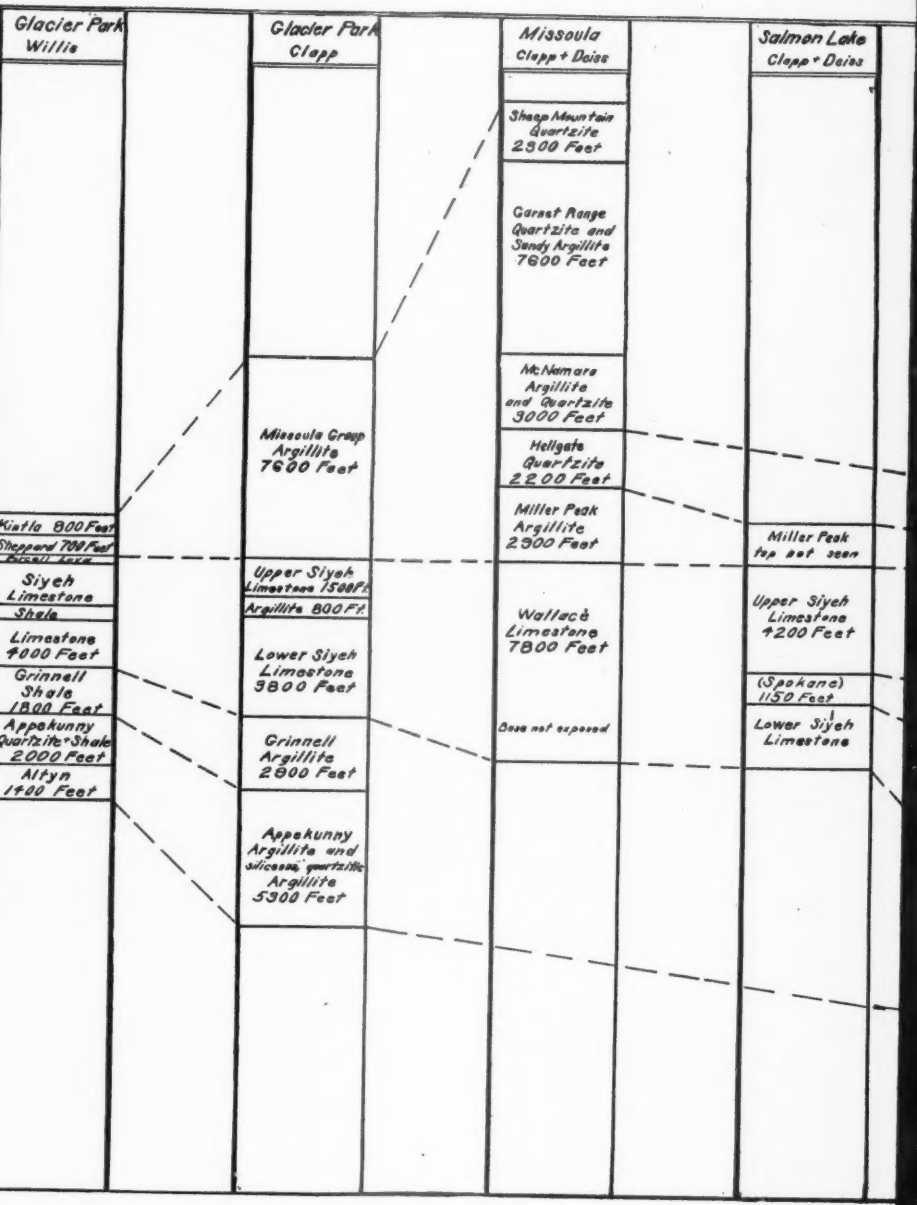


FIGURE 3.—*Correlation Tab*

Prepared by C. H.

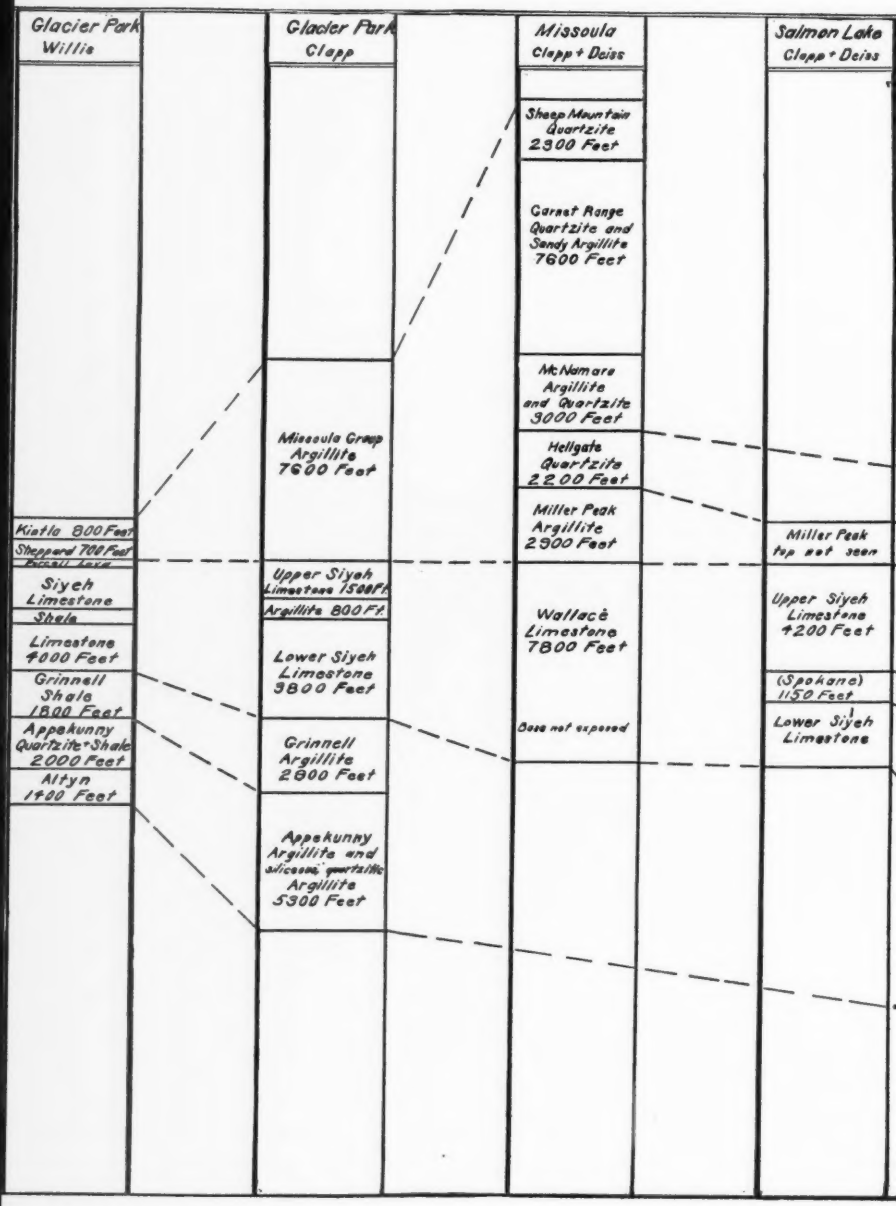
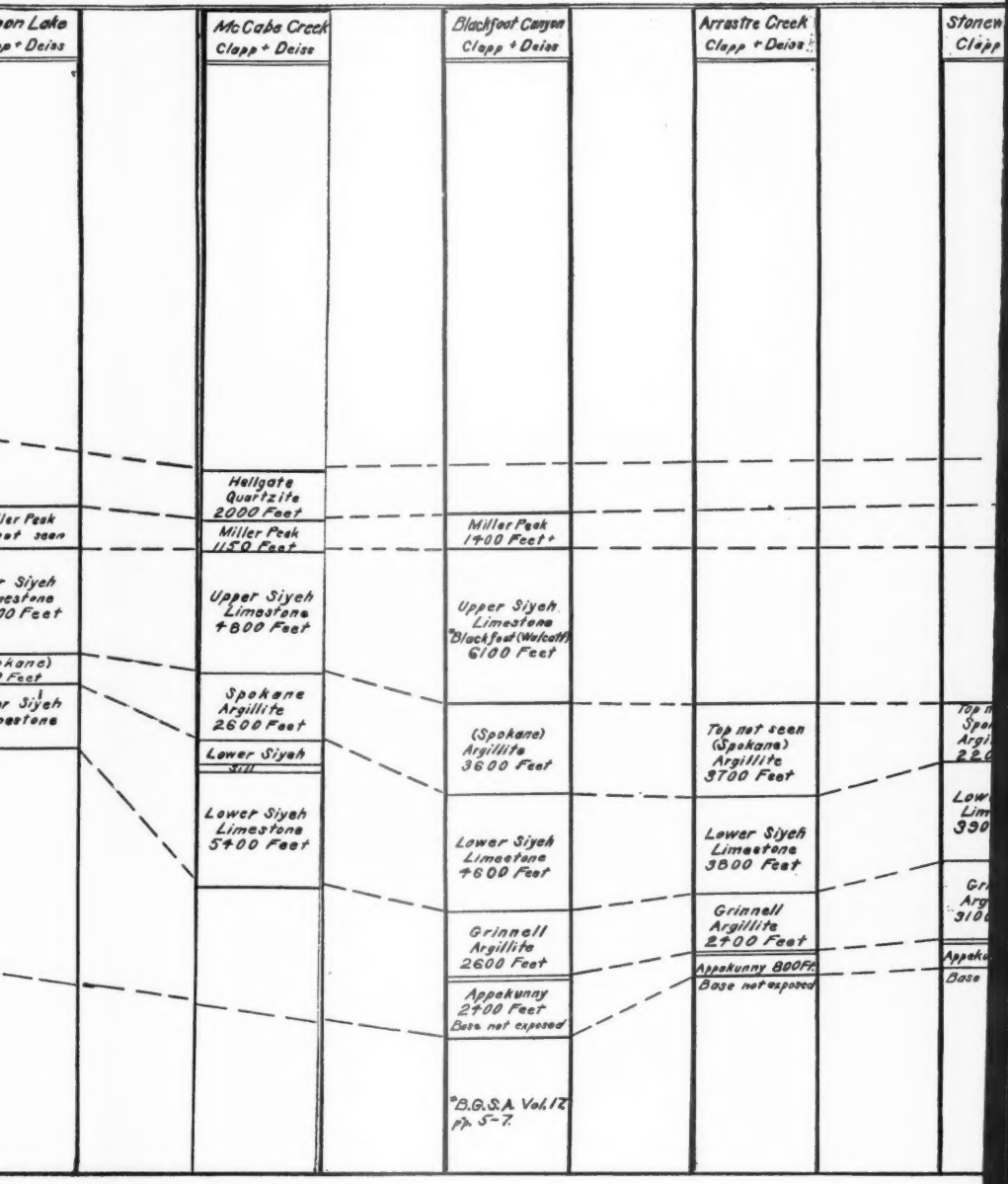


FIGURE 3.—*Correlation*

Prepared by C.



rrelation Table of the Belt Rocks of Montana

pared by C. H. Clapp and C. F. Deiss.

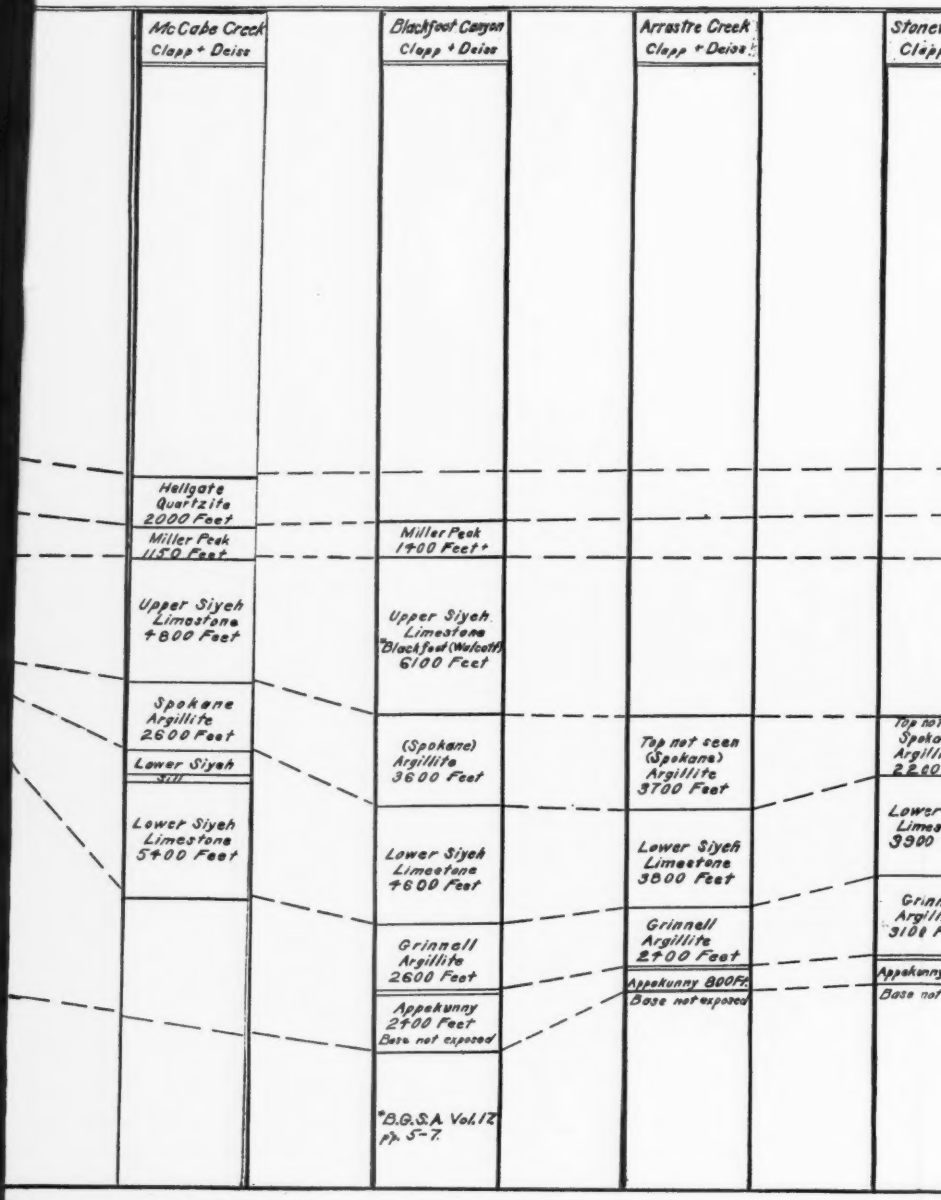
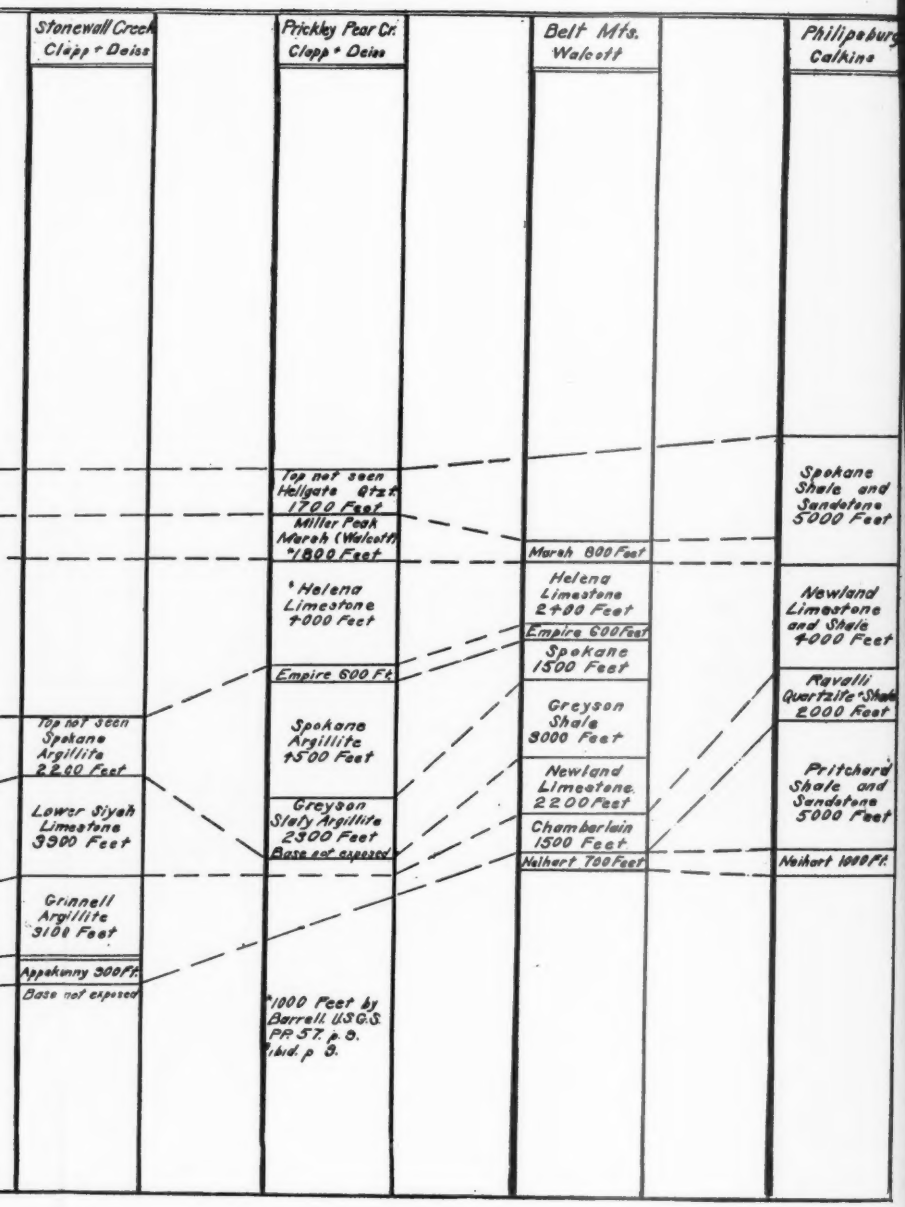


Table of the Belt Rocks of Montana

. H. Clapp and C. F. Deiss.


Stonewall Creek
Clapp + Deiss
Top not seen
Spokane
Argillite
2200 Feet
Lower Siyah
Limestone
3900 Feet
Grinnell
Argillite
3100 Feet
Appekunny 300 Ft.
Base not exposed
Prickley Pear Cr.
Clapp + Deiss
Top not seen
Helgate Qtzt.
1700 Feet
Miller Peak
Marsh (Walcott)
+1800 Feet
*Helena
Limestone
+000 Feet
Empire 600 Ft.
Spokane
Argillite
+500 Feet
Greyson
Slaty Argillite
2300 Feet
Base not exposed
*1000 Feet by
Barrell U.S.G.S.
PP 57 p. 9.
†Ibid. p 3.
Belt Mts.
Walcott
Marsh 800 Feet
Helena
Limestone
2+00 Feet
Empire 600 Feet
Spokane
1500 Feet
Greyson
Shale
3000 Feet
Newland
Limestone
2200 Feet
Chamberlain
1500 Feet
Neihart 700 Feet
Philipsburg
Calkins
Spokane
Shale and
Sandstone
5000 Feet
Newland
Limestone
and Shale
+000 Feet
Ravalli
Quartzite + Shale
2000 Feet
Pritchard
Shale and
Sandstone
5000 Feet
Neihart 1000 Ft.

is thicker, totaling about 2,900 feet. The formations equivalent to the Marsh shale in the more westsern sections are the basal beds of the Missoula group in the Glacier Park section of Clapp, and the Kintla and Sheppard formations in the Glacier Park section of Willis, the lower part of the Missoula formation in the Mission Range section of Wilson, the Gateway formation in the Purcell Range, and the Striped Peak formation in the Cœur d'Alene section.

HELENA LIMESTONE AND ITS EQUIVALENTS

The formations correlated with the Helena limestone of the type section are the Helena limestone in the Prickly Pear Creek section, the Upper Siyeh limestone (Blackfoot of Walcott [32]) of the North Fork of the Blackfoot, the Upper Siyeh limestone of the McCabe Creek, and the Upper Wallace limestone of the Missoula section, the Upper Siyeh limestone of the Glacier Park section of Clapp, the upper part of the Siyeh limestone of the Glacier Park section of Willis, and of the Mission Range section of Wilson, the Siyeh limestone of the Purcell Range section of Schofield, and the upper part of the Wallace limestone of the Cœur d'Alene section.

EMPIRE, SPOKANE, AND GREYSON FORMATIONS AND THEIR EQUIVALENTS

Field investigation has clearly revealed that the Empire shale in the Marysville district is a transition facie of the underlying formation, the Spokane, into the overlying Helena limestone. On the other hand, the Greyson formation seems to have been deposited only in the area of the Belt Mountains, inasmuch as nothing similar to it in lithologic character has been found in any other part of Montana, with the exception of the area 3 miles north of the town of Johns, on Prickly Pear Creek.

The Spokane formation is thickest in the area of Prickly Pear Canyon from 3 miles south of Wolf Creek southward to Johns. In this area about 4,500 feet is exposed. As has been previously mentioned, the Spokane formation thins to the west and northwest. Along the Middle Fork of Flathead River in the southern part of Glacier Park, the Spokane argillites measure 1,980 feet in thickness, whereas in the region adjacent to Bowman Lake in the northwestern part of Glacier Park the Spokane totals only 300 feet in thickness. The thinning of the red Spokane argillites in Glacier Park from southeast to northwest is strikingly illustrated by the section exposed along the new Logan Pass road. At Logan Pass the red argillites are 700 feet in thickness and comprise most of the upper portions of Reynolds and Clements mountains, although the summits are

[32] C. D. Walcott: Op. cit., pp. 5-7.

composed of normal buff-weathering, blue-gray limestone. The red argillites are well exposed in the Garden Wall, north of Logan Pass, dipping to the northwest. Six miles northwest of Logan Pass, 1,000 to 2,000 feet southeast of the switchback, the argillites are only 160 feet in thickness.[33]

This band of argillites (Spokane) becomes somewhat thicker to the west of Glacier Park, in the Cœur d'Alene and Purcell ranges. Calkins[34] describes the Wallace formation in the Cœur d'Alene district as follows: "The lower part (of the Wallace) is composed chiefly of green slate containing more or less carbonate; the middle part of thin alternating layers of impure limestone, bluish and greenish-gray argillites, and a light-colored indurated calcareous sandstone or quartzite; and the upper part chiefly of more or less calcareous argillite with some thin laminæ of limestone." Further, in the description of the Siyeh formation in the Purcell Range, Schofield[35] states: "The lower part of the Siyeh formation is composed of thin-bedded green and purple mud-cracked metargillites and sandstones. About 2,000 feet above the base of the Siyeh formation occur thin-bedded and massive siliceous and concretionary limestone, gray on fresh fracture and weathering usually buff color. These limestones, which are about 1,000 feet thick, are succeeded by purple and green mud-cracked metargillites in thin beds."

From these two descriptions, it is clear that although the Spokane argillite is much thinner in the western ranges than in the Belt Mountains, it is nevertheless a persistent formation.

The formations in the other sections of Algonkian rocks which are correlated with the Spokane of the type section are the red and green argillite and quartzite beds which underlie the Upper Siyeh limestone in the Stonewall Creek, Arrastre Creek, canyon of the North Fork of the Blackfoot River, McCabe Creek, and Salmon Lake sections. The name Spokane formation is carried over from the Belt Mountain section and is used to designate these red and green rocks in the above sections. In the Glacier Park section of Clapp, the Spokane is represented by an average of 800 feet of red sandy argillites which occur as one unit, being overlain by the Upper Siyeh limestone and lying upon the Lower Siyeh limestone, both contacts being normal.

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[33] Figures taken from the manuscript of C. H. Clapp, on his work in Glacier Park, to be published by Montana Bureau of Mines and Geology.

[34] F. L. Ransome and F. C. Calkins: The geology and ore deposits of the Cœur d'Alene District, Idaho. U. S. Geol. Survey, Prof. Paper 62, 1908, p. 25.

[35] S. J. Schofield: Relationship of the Pre-Cambrian (Beltian) terrain to the Lower Cambrian strata of southeastern British Columbia. Bull. 35, Canada Geol. Survey, Geol. Series No. 42, 1922, p. 11.

In the Wallace limestone of the Missoula and Cœur d'Alene sections, in the Siyeh limestone of the Purcell Range section of Schofield, and the Mission Range section of Wilson, argillite bands are intercalated between limestone members throughout the formation. However, in the medial portions of the limestone formations in each of these sections, there is a distinct argillite zone.

NEWLAND LIMESTONE AND ITS EQUIVALENTS

The Newland limestone which underlies the Greyson formation in the Belt Mountains is correlated with the Lower Siyeh limestone of the Stonewall Creek, Arrastre Creek, North Fork of the Blackfoot River, McCabe Creek, Salmon Lake, and Glacier Park (Clapp) sections, and with the Lower Wallace limestone of the Missoula section, the lower part of the Wallace of the Cœur d'Alene section, and the lower part of the Siyeh limestone of the Mission Range section of Wilson. The Kitchener formation of the Purcell Range section of Schofield is also correlated with the Newland limestone of the Belt Mountains.

CHAMBERLAIN ARGILLITE AND ITS EQUIVALENTS

The formation underlying the Newland limestone in the type section is the Chamberlain shale, which is correlated with the Grinnell argillite and the underlying Appekunny quartzite and argillite in the Stonewall Creek, Arrastre Creek, North Fork of the Blackfoot River, and in the Glacier Park section of Clapp. In the Glacier Park section of Willis,[36] the Altyn limestone forms the base of the section, and is tentatively considered along with the overlying Appekunny and Grinnell formations as the equivalent of the Chamberlain in the Belt Mountains. The Saint Regis, Revett, and Burke formations of the Cœur d'Alene section are correlated with the Creston quartzite of the Purcell Range, which is considered the equivalent of the Ravalli formation of the Mission Range, which in turn is correlated with the Grinnell and Appekunny formations and therefore with the Chamberlain in the type section.

Formations equivalent to the Chamberlain shale are absent in the Prickly Pear Creek, McCabe Creek, Salmon Lake, and Missoula sections owing to the fact that in these sections rocks beneath the Lower Siyeh (Wallace) limestone are not exposed.

[36] Bailey Willis: Stratigraphy and structure, Lewis and Livingston ranges, Montana. Bull. Geol. Soc. Am., vol. 13, 1902, pp. 321-324.

PRITCHARD AND ALDRIDGE FORMATIONS

The Pritchard formation of the Cœur d'Alene section is the equivalent of the Aldridge formation of the Purcell Range section of Schofield.[37] No formations of similar stratigraphic position are exposed in any of the other regions in Montana with the exception of that of Philipsburg, which will be discussed later. In the type section the Chamberlain lies directly upon the Neihart, there being no equivalent formation to the Aldridge or Pritchard. Two explanations are possible. Either the Neihart quartzite is the equivalent of the Pritchard in the western sections, or no deposition occurred in the Belt Mountains area during the time the Pritchard detritals were being laid down farther west. The latter postulate gains support from two factors: 1. The Pritchard is very thick everywhere it is exposed, and its base is not known in the Cœur d'Alene and Purcell ranges. 2. The Neihart lies directly upon the Archean rocks in the Belt Mountains.

PHILIPSBURG SECTION

The correlation of the formations of the Philipsburg section with those of the Belt Mountains section is made difficult by the complexity of the structure in the former region, and by the obscurity of the formations resulting from the metamorphism caused by the intrusion of the Philipsburg batholith.[38]

The uppermost formation, the Spokane, is given by Calkins as 5,000 feet in thickness. Of this 5,000 feet, the lower 1,000 feet are correlated with the Marsh shale of the type section, and with the lower part of the Miller Peak formation of the Missoula section, whereas the upper 4,000 feet of the Spokane of the Philipsburg section is correlated with the upper part of the Miller Peak, and with the Hellgate formation, also of the Missoula section.

The Newland formation in the Philipsburg area represents both the Helena and the Newland limestones of the Belt Mountains. The equivalent formations of the Spokane and Greyson in the type section have not been definitely described in the Philipsburg region, although the occurrence of shales or argillites are mentioned as occurring in the Newland formation.[39]

The Ravalli formation is but poorly exposed in the Philipsburg area, and is correlated with the Chamberlain shale of the Belt Mountains.

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[37] S. J. Schofield: Op. cit., p. 11.

[38] F. C. Calkins and W. H. Emmons: U. S. Geol. Survey Atlas, 1915, Philipsburg Folio, No. 196.

[39] W. H. Emmons and F. C. Calkins: Geology and ore deposits of the Philipsburg Quadrangle. U. S. Geol. Survey, Prof. Paper 78, 1913, p. 42.

The Pritchard argillite and quartzite as noted previously is correlated with the Aldridge, and with the Pritchard formations of the Purcell Range and Cœur d'Alene sections respectively, and has no representative in the Belt Mountains.

NEIHART QUARTZITE AND ITS EQUIVALENT

The Neihart quartzite has been correlated with the formation of the same name in the type section. The base of the Neihart quartzite is not exposed in the Philipsburg area. Stratigraphically there is no equivalent formation to the Neihart in any other known section in Montana.

SUMMARY

The stratigraphic correlation of the different sections of the Algonkian rocks in Montana by Walcott, Calkins, and others have been objected to by several men who have worked on these rocks in the field.

In an attempt to solve the problem of the relative stratigraphic position of these rocks, the authors considered that the continuity of the strata was the safest and the only sure means of solving the problem.

Two major conclusions have been reached: First, that overlying the equivalent of the Helena limestone in the western ranges of Montana is a group of clastic rocks 18,000 feet in thickness which have been called the Missoula group; second, that when the formations of the type section of the Belt rocks were traced westward, it was discovered that the Helena and Newland limestones merge, to form the Upper and Lower Siyeh limestone of the western ranges; and that the combined Grayson, Spokane, and Empire formations, separating the Helena and Newland limestones of the type section, thin westward until they can no longer be recognized as mappable formations in the area of the Cœur d'Alene Mountains.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

ORISKANY AT SUSQUEHANNA GAP, PENNSYLVANIA[1]

BY BRADFORD WILLARD[2]

(Read before the Paleontological Society, December 30, 1930)

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INTRODUCTION

Little Mountain forms a small, secondary ridge parallel to and lying along the northern base of Blue Mountain where Susquehanna River has cut its water gap through the ranges north of Harrisburg, Pennsylvania. This topographic feature appears first about 2 miles east of the Susquehanna, and continues westward beyond the river into Perry County. Its development suggests some structural peculiarity. At the crest of Little Mountain west of Susquehanna River occur beds here assigned to the Oriskany, although the bulk of this ridge is composed of Middle Devonian strata. The presence of the Oriskany is significant since the absence of Lower Devonian and adjacent beds at Susquehanna Gap has been generally accepted. This absence has been attributed either to nondeposition locally or to subsequent faulting out of any of those beds which may have been deposited, or to a combination of these causes.

[1] Manuscript received by the Secretary of the Geological Society, March 26, 1931.
[2] Published with the permission of the State Geologist of Pennsylvania.

Geology of the Susquehanna Gap Region

STRATIGRAPHY

The formations of this region outcrop in bands trending parallel to the valleys and ridges, in characteristic Appalachian fashion. Those

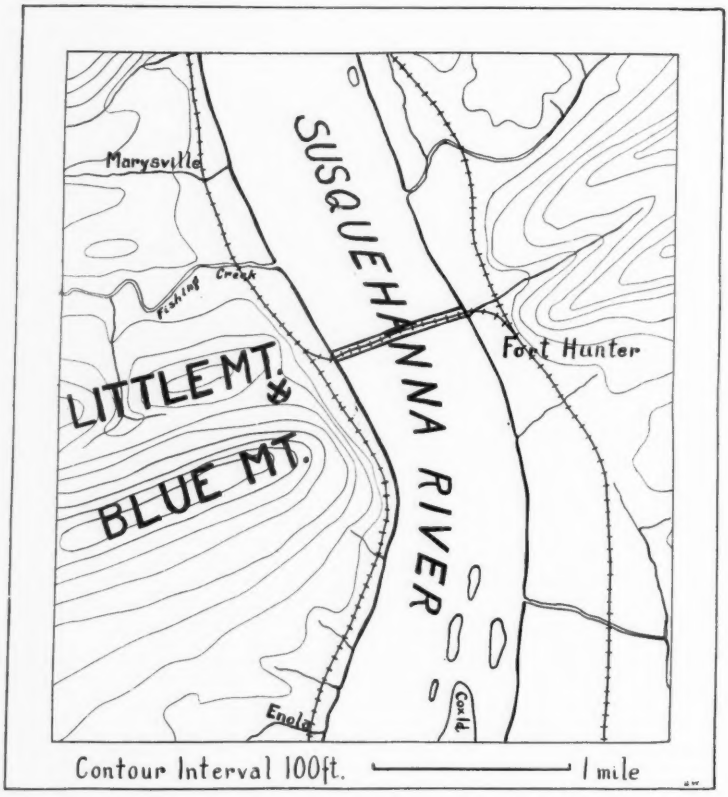

FIGURE 1.—*Sketch Map of the Region of Susquehanna Gap*

recognized at railroad level along the west side of the river from Marysville southward through the gap are:

Devonian:

- Catskill red beds.
- Hamilton-Chemung sandstones and shales.
- Marcellus black shale.

Silurian:

"Clinton" and Bloomsburg (High Falls) red beds.
Tuscarora (Shawangunk) formation.

Ordovician-Silurian(?):

Juniata formation(?).

Ordovician:

Martinsburg formation.

On the east side the same series is exposed except that the Juniata has not been recognized, and the Marcellus makes little or no showing. The Silurian-Devonian contact is probably everywhere hidden, but the concealed interval is small. It hardly exceeds 30 feet on the west side, and on the east the separation is only 5 or 10 feet along the valley eastward above Fort Hunter. From the black Marcellus in the valley between Little and Blue mountains west of the river, there is a transition upward into the Hamilton, this zone being marked by the presence of a species of *Spirophyton,* a condition observed in Maryland.[3] Little Mountain, *judging from the section along the railroad at its base,* consists only of Hamilton-Chemung beds.

STRUCTURES

Most of the beds on both sides of the river at Susquehanna Gap dip steeply southward since they are slightly overturned toward the north. In Little Mountain the dip is about 85 degrees. There is reason to suppose that a concealed thrust fault in and parallel to the valley between Blue and Little mountains has brought Silurian strata on the south or upthrow side into contact with Middle Devonian beds on the north or downthrow side.

INVESTIGATIONS PRIOR TO 1929

The most complete geologic account of the area is that by Claypole[4]; it is confined largely to the west side of the river. His section, interpreted in modern terminology, agrees with that already set down. However, he states (idem, page 314):

"It is worthy of remark that the top of Little Mountain, near this section at Marysville, yields a *Rensselaeria* (or Rensselaeroid brachiopod) which I am unable to distinguish from Hall's *R. Marylandica.* I have found it at

[3] Maryland Geol. Survey, Middle and Upper Devonian, 1913, pp. 62-63.

[4] E. W. Claypole: Second Geological Survey of Pennsylvania, vol. F2, Perry County, 1883, published in 1885.

several places along this range, but this locality is specially valuable because the Oriskany sandstone does not occur within ten or twelve miles of the locality, therefore, there can be no doubt of the rock in which the shell occurs."

The same author elsewhere amplifies this statement.[5] He tells of having showed specimens of his *"Rensselaeria Marylandica"* to James Hall. Hall suggested that the fossil might be *Amphigenia*. If so, the beds should be Hamilton and not Oriskany. Such a determination was satisfactory then, for the attitude of the beds *as exposed at that time on top of Little Mountain* would have seemed to coincide roughly with that of the Middle Devonian strata below along the railroad.

Later, Hall [6] assigned Claypole's *"Rensselaeria"* to the genus *Newberria* and gave it the specific name *Claypolii*. Since there is reason to infer that Hall saw only such Little Mountain material as Claypole showed him, and passed upon this rather hurriedly, his identification is to be taken cautiously. His final determination seems to have been based chiefly on specimens from another locality, for he says (idem, page 264):

"This shell [*Newberria Claypolii*] occurs in great quantities . . . in a coarser pebbly sandstone at Pine Grove, Schuylkill county, in the same State [Pennsylvania], a locality which has furnished most instructive specimens of both the interior and exterior of the shell."

This Pine Grove outcrop is of unquestioned Hamilton age, and the fauna is now believed to be different from that on top of Little Mountain.

Following Claypole and Hall, others investigated the region. Van Ingen [7] studied both sides of the river and thought that the Silurian had been overthrust upon the Middle Devonian, cutting out intervening strata, between Blue and Little mountains. Either he was unaware of Claypole's discovery or he accepted Hall's Hamilton designation of the rocks, for he omits the Oriskany from his list of formations. At the time Van Ingen wrote, the State Geologist, Dr. George H. Ashley, had observed Oriskany-like beds on Little Mountain.[8] The views of Van Ingen and of earlier writers were cited by Eaton,[9] who accepted the Rensselaeroids as *Newberria claypolii*, and the age as Hamilton.

[5] E. W. Claypole: Proc. Am. Assoc. Adv. Sci., vol. 32, sec. E, August, 1883, p. 266. Science, vol. 2, no. 31, September 7, 1883, p. 327. Proc. Am. Phil. Soc., vol. 21, September 1883, p. 235.

[6] J. Hall and J. M. Clarke: Paleontology of New York, vol. 8, pt. 2, 1894, pp. 261-263.

[7] G. Van Ingen: Letter to G. H. Ashley, on file with the Pennsylvania Topographic and Geologic Survey, dated June 24, 1920.

[8] Personal communication.

[9] H. N. Eaton: The Medina problem of southern Pennsylvania, ms. on file with Pennsylvania Topographic and Geologic Survey.

Investigations during 1929 and 1930

Paleontological data

During the summer of 1929 the writer, unfamiliar with Claypole's findings, visited a large, abandoned quarry in the southeast shoulder of Little Mountain on the west side of the Susquehanna, and was surprised to find loose blocks of sandstone, the lithology and fauna of which suggested the Oriskany, although only Middle Devonian rocks were found *in situ*. Being then engaged in a study of the Silurian of Pennsylvania for the State Survey, the writer gave no further attention to the occurrence. During the 1930 field season, he was assigned the study of the Devonian of Pennsylvania, and, remembering the Oriskany-like blocks seen in 1929, revisited the abandoned quarry accompanied by Mr. E. R. Barnsley and later by Mr. S. H. Catheart of the Pennsylvania Survey. The stratigraphic succession along the east side of the river was also checked, but nothing assignable to the Oriskany was discovered. A thorough search west of the river revealed the supposed Oriskany in place at the crest of Little Mountain. From here, talus had evidently fallen into the quarry. The beds are about 30 feet thick and consist of fossiliferous, coarse, friable, whitish sandstone with weak, ferruginous cement which weathers brown or reddish. The outcrop was definitely traced westward along the crest for a quarter of a mile and doubtfully for nearly a mile, beyond which distance no Oriskany was discovered east of Sterrett Gap. It is believed that the following fossils have been recognized among the material collected from these beds:

Rensselaeria marylandica Hall
R. (Beachia) suessana (Hall)
Spirifer cumberlandiae Hall
S. concinnoidcus Schuchert

These species are known from the Maryland Oriskany. *Rensselaeria marylandica* and the two species of *Spirifer* are largely confined to that State; *Rensselaeria* (*Beachia*) *suessana* occurs also in New Jersey and New York. All are found in the Ridgely or Upper Oriskany of Maryland, and *Rensselaeria* (*Beachia*) *suessana* is also listed from the New Scotland of New Jersey. None appears to have survived the Oriskany time. The agreement of the fauna with that of the Maryland rather than with that of the New York Oriskany is significant.

A study of the specimens assigned to *Rensselaeria marylandica* indicates that they are neither *Newberria* nor *Amphigenia*. The largest individuals found are about half as long as the figured examples of *Amphi-*

genia. Although most of the material is poorly preserved in the coarse matrix, a few examples exhibit distinct, external, radiating striations covering the valves, a feature absent in *Newberria* and only faintly present marginally in *Amphigenia.* The fossils lack the strong, concentric growth lines characteristic of both *Amphigenia* and *Newberria.* The in-

FIGURE 2.—*Fault Surface separating Hamilton from overlying Beds*

The locality is at quarry top in Little Mountain. View east along quarry top. Vertical Hamilton at right. Figure stands on fault surface.

ternal casts fail to show features identical with those of these genera, although they suggest more those of *Amphigenia* than *Newberria.* The specimens agree most closely with *R. marylandica,* except for one individual assigned to *R. (Beachia) suessana.* They lack fold and sinus, have a narrow, oval muscle scar confined to the posterior half of the shell, and are "round shouldered," agreeing closely with the published descriptions.[10]

[10] J. Hall: Nat. Hist. of New York, Paleontology, vol. 3, 1861, p. 461. Maryland Geol. Survey, Lower Devonian, 1913, p. 382.

STRUCTURAL RELATIONS

Claypole, puzzled over the apparent occurrence of an Oriskany fauna in what seemed to be a normal succession of Hamilton beds, was handicapped by an incomplete knowledge of the local structures because of lack of exposures. The now abandoned quarry in Little Mountain holds the key to these structures, but it was not in operation until about 1901. Facing nearly south, its northern wall rising abruptly along the steeply-dipping bedding planes of the Hamilton sandstone, the quarry cuts back almost to the crest of Little Mountain. Upon the truncated edges of the

FIGURE 3.—*Detail of Fault Surface at Crest of Little Mountain*

Hamilton at the quarry top, rest a few feet of soft, buff, barren, crushed shale of uncertain age (figure 4). This shale underlies the beds assigned to the Oriskany, but their contact therewith is hidden by talus from the latter. The attitudes of these three members near the quarry top are:

Oriskany:	Strike north 77 degrees east, dip 86 degrees northwest.
Shale:	Strike north 80 degrees west, dip 46 degrees northeast.[11]
Hamilton:	Strike north 80 degrees east, dip 85 degrees southeast.

Here are three adjacent but lithologically different units with dissimilar attitudes. The beds are not noticeably folded, so that faulting seems the best explanation of the disagreement in dips and strikes. Evidence of faulting is present.

[11] The shale is so shattered that these readings are unreliable.

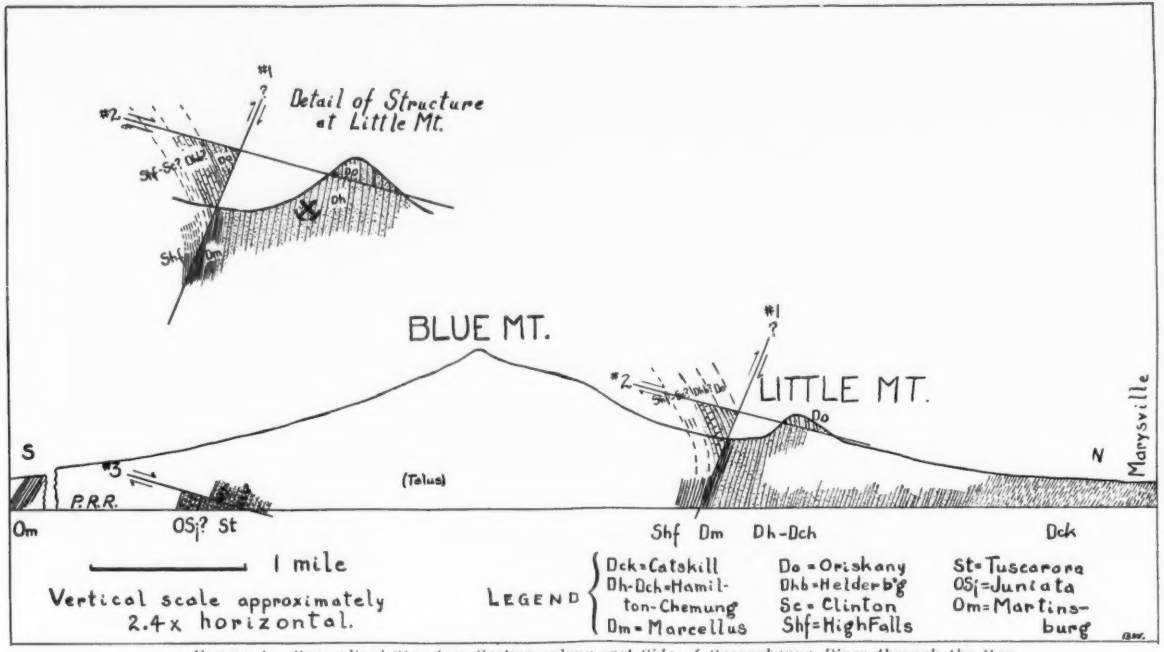

FIGURE 4.—*Generalized Structure Sections along east Side of Susquehanna River through the Gap to Marysville*

Thickness of Oriskany and elevation of fault numbers exaggerated for clarity.

Stripping operations removed the shale from the quarry lip, exposing the truncated Hamilton strata. A cleared surface fully 200 feet long and 5 to 10 feet wide dips under the shale at an angle of about 30 degrees northwest and strikes approximately north 80 degrees east. It is marked by smooth, rounded ridges and troughs, as much as a foot wide and 2 or 3 inches deep, occasionally scored longitudinally by faint striations or grooves and chatter marks that trend down the dip slope. Since the area is well south of the border of maximum ice advance, a glacial origin for these markings is precluded. A fault evidently separates the Hamilton sandstone from the overlying strata. Another fault surface may intervene between the shale and the Oriskany, to judge from the abrupt lithologic change and apparent disagreement of attitudes. On the other hand, the shale may be merely a local variation of the Oriskany, crushed out of its proper attitude because of its own weakness, in which case the existence of a second fault need not be assumed. In the diagrammatic section (number 2, figure 4), only the known fault truncating the Hamilton is shown. The attitude of the observed fault surface is such that the patch of Oriskany rests as a small, local cap on top of Little Mountain. The direction of faulting was, according to observations in the field, probably northward with reference to the Hamilton. The reason for this assumption becomes clear if we consider adjacent displacements.

Van Ingen [12] believed that the valley between Little and Blue Mountains hid another fault. This should strike nearly parallel to the observed Little Mountain fault surface. Because of this movement in the valley, the Silurian has been thrust northward upon the Middle Devonian. This fault surface probably dips steeply southward (number 1, figure 4). The Hamilton and, where present, the Marcellus, form a blunt wedge between the Oriskany and the Silurian. This valley fault presumably cuts out successively higher beds eastward.

It seems necessary to assume that the valley fault is a very steep overthrust northward, for (1) the beds on both sides are overturned in that direction, (2) the Oriskany must have been pushed upward to approximately its known elevation but probably at no great distance from its present resting place, (3) the observed strata adjacent to the fault are found only a few feet apart for a considerable distance vertically, and (4) similar, steep thrust-faults are known in the adjacent region to the north. The valley fault was not contemporaneous with Little Mountain fault. Presumably the Oriskany was first thrust up along the hanging (southern) wall. A succeeding movement along Little Mountain fault

[12] Op. cit.

Thickness of Oriskany and elevation of fault numbers exaggerated for clarity.

shoved at least part of the Oriskany northward to its present position. It is interesting to note that one or more faults in the lower, southern slope of Blue Mountain (number 3, figure 4) cut across the Juniata(?) and Tuscarora formations along surfaces approximately parallel to Little Mountain fault. Probably all of these faults are expressions of movement attending the Appalachian revolution. It is reasonable to believe that faulting may have occurred in different directions at different times.

Summary and Conclusions

Negative evidence was responsible for the former belief that the uppermost Silurian, Lower Devonian, and the lower Middle Devonian were absent at Susquehanna Gap. Some attributed this hiatus to a local cessation of deposition. Another view, supported by considerable field evidence, held the missing beds to have been faulted out. The evidence given in this paper supports a compromise between these two views.

No strata assignable to the uppermost Silurian, the Helderberg, or the Onondaga have been recognized here. Therefore, the presence of Oriskany beds is significant. It indicates local deposition of at least part of the missing formations. The typical appearance of the Oriskany implies normal conditions and suggests that sedimentation may have continued here during the late Silurian and early Devonian times. Furthermore, it may be pertinent to observe that, while the Helderberg may occur independently of the Oriskany in Pennsylvania, the converse is seldom true. The limited fauna shows strong Maryland rather than New York affinities, implying closer southern than northern connections. Sixty to seventy miles to the north, the Oriskany carries a typical New York fauna, and seems to lack the Maryland types. Possibly this is due to a barrier or to environmental differences between adjacent regions or to some other, undiscovered cause. Present studies have not progressed sufficiently far in the intervening region to warrant a definite statement on this phase of the question.

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BIOHERMS IN THE BORDEN GROUP OF INDIANA[1]

BY PARIS B. STOCKDALE

(Read before the Paleontological Society, December 31, 1930)

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INTRODUCTION

The chief stratigraphic perplexities of the Floyds Knob and Edwardsville formations of the Borden (Knobstone) group in Indiana result from the presence of several large, disconnected and irregularly distributed masses of calcareous rock inclosed in clastic strata. These masses, which are dominantly crinoidal limestone, are fittingly designated by the term "bioherm" which has been proposed by Cumings and Shrock.[2] Like buried coral reefs, they have caused unnecessary confusion because of inadequate understanding of their nature and stratigraphic associations. The writer's attention was drawn to these structures during a study of the stratigraphy of the entire Borden group of southern Indiana.[3]

[1] Manuscript received by the Secretary of the Geological Society March 26, 1931.

[2] E. R. Cumings and R. R. Shrock: Niagaran coral reefs of Indiana and adjacent states and their stratigraphic relations. Bull. Geol. Soc. Amer., vol. 39, 1928, p. 599. Discussion of the origin and significance of the term "bioherm" is presented later in this paper.

[3] Complete results of the writer's investigation of the Borden group have been presented in a report, "The Borden (Knobstone) rocks of southern Indiana," to be published by the Indiana Department of Conservation, Division of Geology (in press).

Stratigraphy of the Borden Group of Indiana

THE GROUP AS A UNIT

A brief summary of the major features of the Borden stratigraphy is here presented. The Borden group of Indiana comprises the lower Mississippian rocks between the Rockford (Kinderhook) limestone beneath and the Harrodsburg (Warsaw) limestone above. Prior to the proposal of the name "Borden" by Cumings[4] in 1922, the rocks were designated by the term "Knobstone." The group is within the Osage limits, but apparently is not conterminous with the entire Osage of the Mississippi Valley. The thickness of the Borden in its unglaciated outcrop area of southern Indiana ranges from more than 400 feet at the south to 765 feet at the north.

The rocks of the Borden group are predominantly clastic—fine-grained sandstones, siltstones, and shales. Variations from this are seen in the calcareous facies of the thin Floyds Knob formation; the prominent bioherms and certain restricted members and facies of the Edwardsville formation; and infrequent, thin calcareous layers and patches (miniature bioherms) found irregularly distributed throughout the group. The Borden group is at most places in Indiana fairly sharply delimited both below and above, and is markedly dissimilar in lithologic characteristics from the underlying and overlying strata. The greatest exception to this is in the uppermost part of the group in southeast Harrison County where the topmost calcareous facies of the Borden (Stewarts Landing facies of the Edwardsville formation) and the overlying siliceous limestone of the Harrodsburg are very similar.

STRATIGRAPHIC DIVISIONS AND FACIES

The Borden group is subdivided into five formations, as follows:

Edwardsville
Floyds Knob
Carwood
Locust Point
New Providence

The New Providence formation is mainly argillaceous shale or claystone, ranging in thickness from 190 to 290 feet. On the whole it has been fairly well studied and differentiated as far as the Indiana occurrence is concerned. The less argillaceous rocks of the Borden group

[4] E. R. Cumings: Nomenclature and description of geological formations of Indiana. Indiana Department of Conservation, Division of Geology, Handbook of Indiana Geology, pt. 4, 1922, p. 487.

above the basal New Providence have been much less understood and have been badly confused. Connected field tracing of these rocks has resulted in a fourfold subdivision, each division, however, displaying pronounced lateral differences in lithology and sequence of beds.[5]

The Locust Point formation is mainly massive or shaly siltstone in the southern part of the Indiana outcrop area. Northward the formation becomes a succession of fine-grained sandstone beds and alternating shaly zones. Fossils are rare, aside from worm marks. The average thickness of the formation is about 125 feet. The overlying Garwood formation is much more complex. At the south, in Indiana, it is at most places a massive, fine-grained sandstone or siltstone. Here and there a silty facies displays a shaly appearance where weathered. The formation is highly fossiliferous at some localities; most commonly, however, it is lacking in fossils other than worm marks. The fossiliferous patches of the sandy facies of the southern area carry a fauna characterized by large brachiopods, with *Syringothyris textus, Orthotetes keokuk,* and various species of *Productus* prominent. The more silty facies, where fossiliferous, are featured by abundant bryozoans, mainly species of *Fenestella, Polypora, Cystodictya, Pinnatopora, Rhombopora.* In the northern part of the unglaciated outcrop area the Carwood formation displays a number of lithologic facies varying from argillaceous shale and shaly siltstone to a bedded succession of thin, resistant sandstone beds and shaly layers. Locally, abundant bryozoans occur in patches in the argillaceous phases. The more sandy sediments are practically devoid of fossils, aside from worm marks and *Taonurus* which are locally profuse. The Carwood formation ranges in thickness from 105 to 150 feet.

The Floyds Knob formation is the key unit in subdividing the upper Borden rocks and correlating the units of southern Indiana with those of adjacent parts of Kentucky. It exhibits several lithologic facies. The most common is a limestone which varies markedly from place to place. Throughout the southern half of the unglaciated Indiana outcrop belt, and in adjacent parts of Jefferson County, Kentucky, the formation varies from fairly pure crinoidal, oolitic, or crystalline rock to ferruginous, siliceous limestone. The thickness averages 3 to 4 feet. In Jefferson County, Kentucky, and adjoining regions, the formation is the one described by Butts as the "layer of oolite" at the "base of the Warsaw."[6]

[5] Definite proposals for the stratigraphic subdividing of the Borden group and the naming of the several units and their facies are made by the writer in the previously mentioned forthcoming Indiana report. See footnote no. 3.

[6] Charles Butts: Geology and mineral resources of Jefferson County, Kentucky. Kentucky Geol. Survey, ser. 4, vol. 3, 1915, pp. 157-158. The Mississippian series of eastern Kentucky. Kentucky Geol. Survey, ser. 6, vol. 7, 1922, p. 73.

Locally, in southern Indiana the formation is a sandstone. North of township 6 north in Indiana, the formation is a peculiar mixture of calcareous, ferruginous, cherty, shaly rock. Extending upward from this, locally, and involving the basal portion of the overlying Edwardsville formation are the prominent bioherms of the Edwardsville formation, mainly in Monroe and Morgan counties, Indiana.

The Edwardsville is in many respects the most unique of all Borden formations. It displays the greatest thickness range—40 to 200 feet. It is predominantly a formation of shale, siltstone, and sandstone. A perplexing calcareous lithology at the extreme south end of the Indiana outcrop area and in adjacent Kentucky renders it easily confused with the basal member of the overlying Harrodsburg limestone.

RELATIONS BETWEEN THE FLOYDS KNOB AND EDWARDSVILLE FORMATIONS

South of northern Lawrence County, Indiana, the Floyds Knob formation (usually a limestone) is at most places clearly demarcated from the overlying Edwardsville unit. North of northern Lawrence County through eastern Monroe, western Brown, and southern Morgan counties, the Floyds Knob formation is at many places not separable from the basal Edwardsville rocks above because of lithologic similarities between the two divisions. At some places in this northern region, however, the Floyds Knob formation is clearly demarcated and easily recognizable where it is: (*a*) a hard, brown, crinoidal limestone bed, 2 to 3 feet thick; or (*b*) a thin zone of irregular, slightly calcareous rock, brittle, shaly, and arenaceous, usually with lumps of chert, commonly exposed in a partially weathered form with a light buff, yellow, or even chocolate-colored hue. In a few places the formation is no more than a thin band of limestone conglomerate resembling that of numerous exposures near the type locality to the south. These facies grade into one another. At those places where the boundary between the Floyds Knob formation and the overlying Edwardsville can not be ascertained, one of two situations commonly exists; (*a*) an irregular zone, built up from the base of the Floyds Knob, which is devoid of any definite limestone lenses but consists of slightly calcareous, brittle, sandy shale usually carrying chert lumps and small geodes, considerably thicker than the normal Floyds Knob unit (as much as 25 feet or more); (*b*) a limestone mass extending from the Floyds Knob base up into the overlying Edwardsville formation to a height as great as 70 feet, formed where organisms, particularly crinoids, established themselves in restricted patches for a prolonged time. The latter are the bioherms. Stratigraphic confusion and mis-

interpretations of geologic structure have been an outgrowth of erroneous presumptions that various limestone beds and calcareous zones exposed in different sections were at the horizon only of the thin Floyds Knob formation.

The Borden Bioherms

THE TERM "BIOHERM"

In proposing the term "bioherm" in 1928, Cumings and Shrock wrote:

"The terms *reef* and *coral reef* are both more or less misleading. Reef has many other connotations, and *coral reef* encourages the common misconception that reefs are largely made of coral, whereas many of them were formed by other organisms, such as algae, hydrozoans, crinoids, mollusks, et cetera. The authors have for some time used the term 'bioherm,' from the Greek root βιο, having the meaning organic, and ἔρμα the word for a reef. . . . The word bioherm is formed on the analogy of such words as endoderm, echinoderm, et cetera." [7]

Cumings later carefully defined the structures indicated by the term as follows:

"The term *bioherm* . . . is defined as consisting of *any dome-like, mound-like, lense-like or otherwise circumscribed mass, built exclusively or mainly by sedentary organisms such as corals, stromatoporoids, algae, brachiopods, molluscs, crinoids, etc., and enclosed in normal rock of different lithologic character.*"[8]

The term "bioherm" is particularly suitable for the calcareous, organically made masses which are so prominent in the upper Borden rocks, especially those in the lower part of the Edwardsville formation. This is distinctly true inasmuch as the masses are not of the kind usually indicated when the terms "reef" or "limestone lens" are applied in stratigraphic discussions.

DESCRIPTION

The most important and largest Borden bioherms are built up from the Floyds Knob formation and extend up into the Edwardsville. However, small, uneven limestone masses, featured by abundance of crinoid stem segments, occur distributed sporadically in the Carwood formation. These masses are but a few feet in diameter and are inclosed in most instances by siltstone. Interesting occurrences of such masses are seen along the road at Holtsclaw Hill, Jefferson County, Kentucky, 28 feet

[7] E. R. Cumings and R. R. Shrock: Op. cit., p. 599.

[8] E. R. Cumings: List of species from the New Corydon, Kokomo and Kenneth formations of Indiana, and from reefs in the Mississinewa and Liston Creek formations. Proc. Indiana Acad. Sci., vol. 39, 1930 (1929), p. 207.

beneath the top of the "Holtsclaw sandstone"; along the road ascending the steep Locust Point hill, southeast Harrison County, Indiana, 45 feet beneath the top of the Carwood formation; along State Highway Number 35, at Millport Knob, north Washington County, Indiana, 15 feet beneath the top of the Carwood formation; and at numerous other places. Occasional small fossiliferous limestone masses up to about 1 foot thick in the New Providence shale may also be thought of as miniature bioherms. Such masses are in some places a compact bed of crinoid segments. Where weathered, the fossils are washed down and strewn profusely over the shale slopes. It was from such crinoid masses that Springer collected and described the crinoid fauna of the New Providence shale.[9]

For several years Indiana workers have been perplexed by a number of disconnected occurrences of heavy crinoidal limestone within the heart of the Borden outcrop belt in eastern Monroe, western Brown, and southern Morgan counties. The "Knobstone" (Borden) of these investigators was thought to be composed entirely of sandstones and shales. Some suspected the limestone beds to be outliers of the Harrodsburg, made possible by local downfolding or faulting. Others looked upon the masses as odd "lenses" in the "Knobstone," but did not have definite knowledge of the exact stratigraphic positions. The stone of some of these beds has been quarried and crushed for road building. In places the limestone exists in such quantities and with sufficient purity to permit development of sink holes (see figure 1) and fair-sized caverns, features extremely unique in the Borden belt.

The writer has found these limestone masses to be bioherms built up in most cases from the base of the Floyds Knob formation (Cisco Branch facies) and extending varying distances into the basal Edwardsville formation (Allens Creek facies). (See figure 2.) They may be as much as 70 feet thick and 2 miles in diameter, but the exact size and shape are usually indeterminable because of insufficient exposures. In ground plan these bioherms are more or less roundish. The bases of the masses are essentially flat and their upper surfaces are no doubt quite uneven. There are lateral offshoots from the main masses furnishing isolated limestone beds at various positions above the horizon of the Floyds Knob in sections exposed near the peripheries of the bioherms. At the margins the limestone grades rather sharply into the inclosing, non-calcareous beds.

[9] Frank Springer: The crinoid fauna of the Knobstone formation. Proc. U. S. Nat. Mus., vol. 41, 1911, pp. 175-208.

Lower Allens Creek of southeast Monroe County cuts across a typical bioherm of the above described type (see figure 2). Good exposures occur in parts of sections 13 and 24, township 7 north, range 1 west, and sections 18 and 19, township 7 north, range 1 east. The center of the bioherm is near the southeast corner of section 13. Here calcareous deposition went on to the greatest height (about 65 feet) above the base of the Floyds Knob formation. One mile to the east, the bioherm is absent

FIGURE 1.—*Sink Hole developed on the Limestone of the Allens Creek Bioherm*

The locality is in northeast ¼ southeast ¼ section 13, township 7 north, range 1 west, 3 miles southeast of Smithville, southeast Monroe County, Indiana. This is a feature unique in the area of Borden rocks.

and the stratigraphic interval is a succession of sandstone beds and shaly zones. Geologic sections between these places show progressively more and more limestone to the west toward the center of the bioherm. The exact size of the structure is not determinable because the western part has been cut away by the valley of Salt Creek. Sections exposed along the west side of the valley, a mile or so to the west of the place of greatest limestone thickness, give no indications of an excessive thickness of limestone. The diameter of the original bioherm was probably not more than

2 miles. Aside from outcrops demonstrating the excessive thickness of the limestone, a large sink hole (see figure 1) in northeast ¼ southeast ¼ section 13, township 7 north, range 1 west, and a good-sized cave in north-center southwest ¼ section 18, township 7 north, range 1 east bear testimony to this unusual mass of limestone.

Figure 2 shows several geologic sections illustrating the nature of a typical Floyds Knob-Edwardsville bioherm, as exemplified by the bioherm in the Allens Creek region. Sections 1, 2, 3, and 4 were taken at intervals of about one-fourth to three-tenths of a mile apart. Section number 1 is at the southeast margin of the bioherm, measured along a secondary road which runs northeast at the abandoned Allens Creek Post Office, southeast ¼ northeast ¼ section 19, township 7 north, range 1 east. The thin Floyds Knob formation is present with a thickness of 1½ feet. There is no limestone above, but instead there is a succession of resistant sandstone beds up to 2 feet thick, and alternating shale zones. Section number 2 was measured in a sharp ravine in the bluff on the south side of Allens Creek, three-tenths of a mile west of section number 1, southwest ¼ northeast ¼ section 19, township 7 north, range 1 east. In this section variable limestone is present up to 29 feet above the base of the Floyds Knob formation. All but the basal 3 or 4 feet of this limestone must be looked upon as belonging to the Edwardsville. Overlying the limestone is normal Edwardsville clastic rock—sandstone, siltstone, and shale. Section number 3, showing 46 feet of calcareous rock above the bottom of the Floyds Knob, was taken from another sharp ravine, one-fourth of a mile northwest of section number 2, at west-center northeast ¼ northwest ¼ section 19, township 7 north, range 1 east. Again, the upper boundary of the Floyds Knob formation can not be demarcated. Some 40 feet of limestone in this section must belong to the Edwardsville division. Section number 4 is near the heart of the bioherm, about four-tenths of a mile northwest of section number 3, at south-center southwest ¼ southwest ¼ section 18, township 7 north, range 1 east. Limestone dominates this section from the base of the Floyds Knob upwards for 62 feet. Nearly 60 feet of the limestone comprises the basal Edwardsville in this section, contrasted with about 40 feet in section number 3, 25 feet in section number 2, and no limestone in section number 1. Section number 5 depicts a readily accessible exposure near the bridge across Salt Creek, one-half of a mile northwest of section number 4. The rocks are exposed in small ravines and along the valley side south of the creek, in east-center section 13, township 7 north, range 1 west. There is a 57-foot zone composed mainly of limestone above the Floyds Knob horizon.

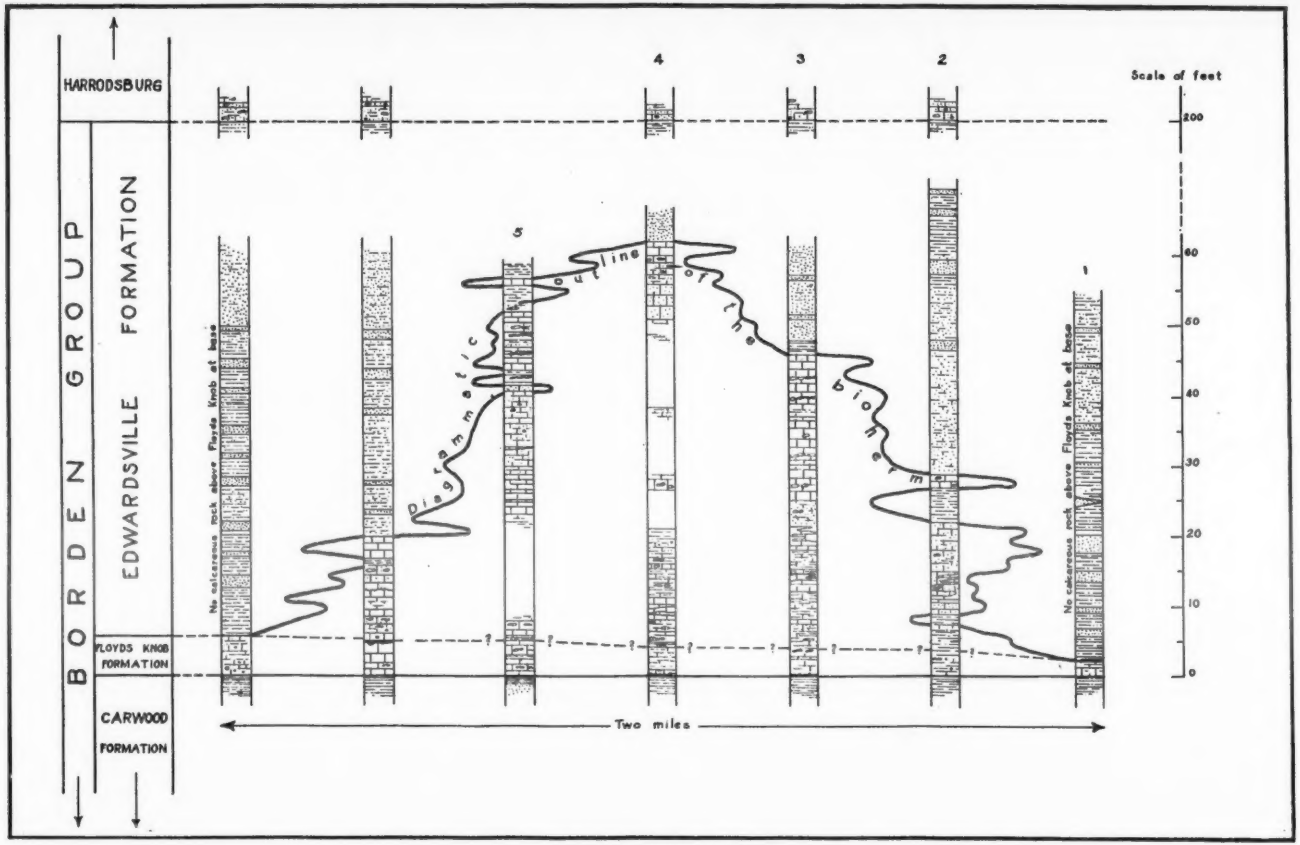

FIGURE 2.—*Geologic Sections*

Illustrating the stratigraphic associations of a typical Floyds Knob-Edwardsville bioherm and the inclosing strata, as exemplified by the bioherm in the Allens Creek region of southeast Monroe County, Indiana. Note the exaggerated vertical scale.

The section is here listed as an example to illustrate the nature of the rocks within the heart of a typical Edwardsville bioherm.

Section number 5 in small ravines and along hillside, south side of Salt Creek valley, near bridge, east-center section 13, township 7 north, range 1 west, southeast Monroe County, Indiana

	Feet
Edwardsville formation:	
Sandstone, siltstone, shale, mostly covered.	
Shale, sandy, buff	5
Limestone, coarsely crinoidal, hard, white	½
Shale, sandy, partly covered	4
Limestone, irregular, mainly coarsely crinoidal, white with brown specks; contains thin layers of brittle, yellow to chocolate-colored siliceous limestone; with much chert, in irregular lenses up to 8 inches thick, and in nodules; some shaly partings	12
Limestone, impure, brittle, siliceous; gray, yellow to brown	8
Limestone, crinoidal	½
Limestone, impure, brittle, siliceous; partly covered	1½
Limestone, in thin slabs, coarsely crinoidal, white with brown specks; contains little chert	7
Covered	15
Floyds Knob formation (in part, at least):	
Limestone, in strong layers, mainly coarsely crinoidal; contains much chert; occasional blue-gray shaly partings; spring at base (under bridge)	8
Carwood formation:	
Shale, blue; with scattered small crinoid stem segments and bryozoans	1¼
Sandstone, single bed	1
Covered (alluvium).	

The Allens Creek bioherm depicted above is not a solid mass of limestone, but instead is one *dominated* by limestone, with intercalated beds of shale which usually carry numerous crinoid fragments. Nor is the limestone all of the same type. Some is quite pure and crinoidal, while some is a "bastard" stone, highly siliceous. Much chert, white to buff, and pale blue chalcedony are features. The exceptional size of the crinoid stem segments is striking. Diameters up to 1¼ inches have been observed. Circular stem plates predominate, but large elliptical ones are common. In some instances crinoid segments which are embedded in the chert or chalcedony have been silicified; in others, curiously enough, they are of calcite. Surrounding the bioherm are clastic beds at the horizons of the different calcareous beds of the bioherm. The dip of these beds is that normal to the region. The base of the bioherm is about

205 feet beneath the Harrodsburg limestone, and the top reaches to within 140 feet of the Harrodsburg. The Floyds Knob formation can not be differentiated, at most places, from the overlying Edwardsville in the bioherm, but perhaps not more than the basal 3 or 4 feet or so of the limestone was built up during Floyds Knob time.

In the Monroe-Brown-Morgan County area, in southern Indiana, there are at least 7 distinct bioherms of the above described type. Well-known exposures of limestone in the vicinity of the old Stobo Post Office, 6½ miles east of Bloomington, are in such a bioherm. The famous "crinoid beds" at Crawfordsville constitute the most notable of the Edwardsville bioherms within the glaciated area farther north.

SIGNIFICANT FEATURES

The Borden type of bioherm differs in several ways from the various kinds of reef structures commonly mentioned in stratigraphic literature. In the first place, inclosure by entirely clastic, noncalcareous sediments is unique. A feature common to practically all well-known "reefs" of our geologic systems is the burial within *limestone* which differs lithologically from that of the reef proper. This is illustrated by the well-known Silurian and Devonian coral reefs of northern Indiana, Ohio, Michigan, Illinois, Wisconsin, and Ontario; the bryozoan reefs of the German Zechstein; the famous Jurassic reefs of Solnhofen, composed chiefly of sponges, corals, and pelecypods; and others. In the nature of the inclosing rock and marginal contacts the Borden bioherms are similar to the "Tepee Buttes," described by Gilbert and Gulliver, which are embedded in the Pierre shales along the Arkansas River and other parts of the Great Plains. The "Tepee Buttes," however, are much smaller and produce a singular topographic effect.

Absence of strongly dipping beds peripheral to the bioherms is another feature that contrasts strongly with coral reefs. There is likewise an absence of a central core flanked by clastic deposits coming from the disintegrated reef. There are intercalated horizontal beds of shale coming into the heart of the bioherms, and tonguelike offshoots of limestone extending well beyond the bioherms proper. Exposures at the margins show subordinate interfingering. On the whole the limestone grades fairly sharply into the adjoining sediments. Thick chert beds are prominent within the bioherms but are absent from the surrounding strata. Evidence points to a syngenetic origin for the chert. All factors seem to testify that the bioherms were built up evenly and contemporaneously

with the inclosing clastic sediments and did not stand up as isolated organic mounds on the sea-bottom as do coral reefs.

Conclusions

One has difficulty in clearly visualizing sedimentary conditions which would permit the making of such structures as the Borden bioherms. The significant characteristics, which indicate that the structures were built on the sea-bottom contemporaneously with the surrounding beds, demand the presence of clear waters covering restricted patches, and surrounding waters which were depositing muds, silts, and sands. It may be likely that the presence of a living, thickly populated crinoid colony, whose footing was once established locally (perhaps accidentally), served to halt or divert feeble bottom currents which were slowly sweeping fine sediments across the sea-floor. From time to time the organic remains may have accumulated to slight heights above the surrounding sea-floor. When, temporarily, the overlying waters became muddy, the clay settled within and on the crinoid colony and formed layers of shale mixed with crinoid segments. A temporary constriction of the organic colony allowed clay deposition to encroach upon the bioherm around the margins, producing intercalated shale beds. Occasionally, the organisms spread somewhat beyond their original confines, producing tonguelike layers of limestone extending into the inclosing zone of clastic sediments. As time progressed, the size of the colony diminished until finally the organisms disappeared and clastic sediments buried the limestone mass.

The existence of much chert in layers between the crinoid beds of the bioherm and an absence of chert in the beds surrounding the structure suggest a possibility of organic secretions playing a part in the flocculation of colloidal silica from the sea water. The silica-jel settled to the bottom and embedded segments of the broken-up crinoids. Where the waters were somewhat turbid and away from organisms, silica was not notably precipitated. The region of bioherm growth was far from land. The Edwardsville rocks, without bioherms, crop out miles to the east, north, and south, and occur buried beneath younger strata on the west. Considerable evidence suggests that the Borden sea of Indiana was continuous with the Waverly sea of Ohio and the Marshall sea of Michigan, and that the source of the clastic sediment was even farther east, or to the north or northeast.

The chief aim of this paper has been to present the characteristic features of the Borden bioherms, with their stratigraphic associations and their bearing upon the problems of the Borden stratigraphy. It is recognized that many of the problems relative to conditions of sedimentation are still unsolved.[10]

[10] The writer is especially indebted to Prof. E. R. Cumings of Indiana University for help in the field, and both to him and to Prof. J. Ernest Carman of Ohio State University for valuable assistance in the preparation of this report.

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BURIED PRE-CAMBRIAN OF WISCONSIN[1]

BY F. T. THWAITES

(Read before the Society December 31, 1930)

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[1] Published by permission of the State Geologist of Wisconsin.
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Introduction

Previous investigations

The attention of the writer was drawn to the nature and form of the buried pre-Cambrian basement of Wisconsin when he began the study and collection of well records for the Wisconsin Geological and Natural History Survey in 1912. The present study of this problem is by no means the first, for in 1869 I. A. Lapham [2] published a map of Wisconsin on which he drew 100-foot contours on the base of the Paleozoic sediments. In 1915 Weidman [3] drew a generalized map of the top of the concealed pre-Cambrian with 250-foot contours. This map omitted all local irregularities. In the following year Jay,[4] working under the direction of Lawrence Martin, mapped small areas near Baraboo. In 1925 Du Rietz [5] published a small-scale contour map of the surface of the pre-Cambrian of North America.

Structure

The pre-Cambrian rocks of Wisconsin form an elongated geanticline which strikes approximately north and pitches gently to the south. The exposed part of this structure forms the highland of northern Wisconsin, where the average bed-rock surface is about 1,600 feet above sealevel. Rocks of Paleozoic age overlap the southern end of this exposed area. This paper deals with the marginal area of pre-Cambrian which is almost completely concealed. In Wisconsin the Paleozoic cover reaches a maximum known thickness in excess of 3,000 feet. As the surface of the older rocks is neither level nor uniform, there are a number of inliers of pre-Cambrian formations within the general Paleozoic area. In other places erosion valleys in the Paleozoic strata have reached the surface of the old basement rocks far from the margin of the younger covering rocks.

Well Records

The nature of the concealed pre-Cambrian rocks may be (*a*) inferred from inliers and (*b*) determined from borings. Table 1 summarizes records of wells from which the pre-Cambrian rock has been actually seen in samples. Nearly all of the records are of water wells, for mineral

[2] I. A. Lapham: A new geological map of Wisconsin, Milwaukee, 1869.

[3] Samuel Weidman and A. R. Schultz: The underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915 (map in pocket).

[4] E. L. Jay: The pre-Cambrian drainage of the Baraboo region with special reference to the Devils Lake Gap. Unpublished thesis, Library of the University of Wisconsin, 1916.

[5] T. A. Du Rietz: The deformation of the pre-Cambrian peneplain of North America. Geol. Fören., Stockholm Förhandl., bd. 47, 1925, pp. 250-257.

exploration drill holes have been put down in so few places that full description of their results is not needed for the present study. In drawing the map, records of other wells in which it seems reasonably certain that pre-Cambrian rock was encountered were used (Table 2). In records where samples are not available the writer has used considerable caution in accepting the statements of well drillers, for mistakes have undoubtedly been made in concluding that "hard rock" has been reached through misinterpretation of slow drilling. Slow progress with a churn drill may be due to several causes other than hardness of the rock: (*a*) crooked hole in which the blows of the tools are lessened in strength, (*b*) drilling in a crevice where the bit always strikes in the same place, (*c*) encountering sandstone which is so pure that the cuttings will not stay in suspension, and (*d*) encountering sandstone with shale layers which cause the sand to stick to the bit and the walls of the hole. Another class of errors may be charged to dishonest representations by the driller who was anxious to finish a job. In some cases where either (*a*) the sample submitted is mixed with a large quantity of sand cavings, or (*b*) the sample consists of finely pulverized quartz, even a geologist is in some doubt. In the latter case it must be remembered that real quartzite usually cuts into chips, many of which are over 1 mm. in diameter. Very fine quartz flour is almost invariably derived from sandstone which has been pulverized by the drill. Another error, for the most part relatively small in magnitude, is mistaking the decomposed surface of the pre-Cambrian for Cambrian shale. Most of the cuttings from the pre-Cambrian could be identified with a hand lens, but a few were made into thin sections for determination with the petrographic microscope. Through a study of well records and the distribution of drift boulders, the area known to be underlain by the old hard rocks has been considerably increased in northeastern Wisconsin.[6]

[6] E. F. Bean. Geological map of Wisconsin, 1928.

TABLE 1

Well records showing nature of concealed pre-Cambrian rocks in Wisconsin; samples have been examined by geologists

Map number—city.	Owner or location.	Surface elevation.	Depth to pre-C.	Pre-C. elevation.	Rock; remarks.
1. Baraboo	City test well	856	424	432	Quartzite
2. Barron	City	1,120	420	700	Quartzite or conglomerate
3. Black Creek	Borden Co.	785	512	273	Granite under drift
4. Bloomer	Armour Co.	1,006	170	836	Granite
5. Casco Junction	G. B. & W. R. R.	728	1,675	—947	Granite
6. Clintonville	City test well	825	140	685	Granite under drift
7. Delavan	Bradley Knitting Co.	938	1,660?	—720?	Quartzite? or sandstone
8. Eleva	Jackson farm	900	334	566	Basalt
9. Fond du Lac	City test well	750	740	10	Quartzite, slate, etc. (Table 4)
	Galloway West Co. No. 1	760	440	320	Quartzite (Table 4)
10. Friendship	Oil test	960?	265	655?	Gneiss, granite
11. Gillett	Gillett Canning Co.	801	412	389	Hornblende schist
12. Green Bay	City	590	855	—265	Granite
13. Hartford	City, several wells	985	532	453	Quartzite (Table 4)
14. Hubbleton	Exploration holes:				
	T.9, R.14E., NE¼, SW¼, 31	790	614	176	Slate, quartzite[a]
	SE. ¼, SE. ¼, 31	785	457	328	Slate, quartzite
	SW. ¼, NE.¼, 15	800	753	47	Dolomite, slate, schist, quartzite
15. Hudson	City	670	393	277	Basalt
16. Jefferson	Carnation Milk Co.	790	825	—135	Quartzite
17. Jefferson Junction	Ladish Stoppenbach Co.	820	879	—59	Granite
18. Juneau	Libby, McNeil & Libby	910	730	180	Quartzite
19. Kaukauna	City	650	805	—155	Granite (tube)
20. Kewaskum	Rosenheimer Co.	950	1045	—95	Quartzite
21. Kilbourn	Exploration	928	450	478	Basalt, etcetera (Table 3)
22. La Crosse	City	640	467	173	Granite[b]
23. Madison	City No. 10	851	731	120	Basalt[c]
	No. 11	850	733	117	Basalt

	No. 11	850	733	117	Basalt
	No. 12	856	835	21	Granite
	No. 13	851	730	121	Basalt
	No. 14	850	730	120	Schistose rhyolite
	No. 15	854	715	139	Rhyolite
	Capitol	929	800	129	Basalt[d]
	Kennedy Dairy Co.	863	740	123	Basalt
	C. M. St. P. & P. R. R.	863	790?	73?	Basalt[e]
	Nine Spring Sewage Disposal Plant, SE.¼, SW¼ 30, T.7, R. 10 E.	892	825	67	Basalt
24. Marinette	City	590	712	—122	Quartzite[f]
25. Mather	Appleton Cranberry Co., sec. 20, T. 21, R. 1 E.	1,000	175	825	Basalt
26. Mayville	Youngstown Sheet & Tube Co., No. 2	920	1,160	—240	Jasper
27. Mount Calvary	Monastery	1 060	1,176?	—116?	Quartzite[g]
28. Necedah	C. & N. W. Ry. Co.	905	310	595	Granite
	Exploration hole No. 1	905	229	676	Diorite[h]
	No. 2	905	202	703	Granite, diorite
	No. 3	905	192	713	Diorite
	No. 4	905	203	702	Quartzite, granite
29. Oconomowoc	Montgomery Ward	896	950	—54	Quartzite[i]
30. Oil City	Oil test	890	490	400	Granite[j]
31. Oshkosh	Algoma Street	755	680	75	Granite
	Diamond Match Co.	755	675	80	Granite[k]
	State hospital	765	714	51	Granite[l]
32. Pewaukee	Edgewood farm	860	1,190	—330	Granite
33. Portage	Court House	819	530	289	Rhyolite[m]
34. Prairie du Sac	Phillip farm	859	560	299	Granite
35. Pray	Adbar exploration, sections 1 and 2, T. 21, R. 2 W.	950	85–98	860	Iron formation and schist
36. Reeseville	Etscheid farm	850?	93	757	Quartzite (Table 4)
37. Sauk City	City	757	523	234	Granite

Map number—city.	Owner or location.	Surface elevation.	Depth to pre-C.	Pre-C. elevation.	Rock; remarks.
38. *Stillwater, Minn.*	Gas test	850	705	145	Sandstone, etcetera[n]
39. Tomah	Park	980	353	527	Gneiss
	City, north well	955	310	645	Granite
40. Two Rivers	City test well No. 2	587	1,610	—1,023	Quartzite (Table 5)
41. Watertown	City No. 2	809	750	59	Slate[o]
	No. 3	809	715	94	Iron formation
42. West Bend	City	920	930?	—10?	Chert?
43. Waupun	City	883	750	133	Pegmatite
	Insane hospital	880	509	371	Quartzite
44. Whitehall	City	815	265	550	Gabbro

[a] Data from files of C. K. Leith.

[b] Moses Strong: Geology of the Mississippi Region. Geology of Wisconsin, vol. 4, 1882, pp. 60-61, 520.

[c] O. U. Stromme: Geology of Madison and parts of adjacent townships. Unpublished thesis, Library of University of Wisconsin, 1907.

[d] I. A. Lapham: Ann. Rep. for 1874. Geology of Wisconsin, vol. 2, 1877, p. 50.

[e] R. D. Irving: Geology of central Wisconsin. Geology of Wisconsin, vol. 2, 1877, p. 605.

[f] R. A. Smith: Deep well borings. Michigan Geol. Survey, Pub. 24, 1917, pp. 238-239.

[g] Samuel Weidman and A. R. Schultz: The underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915, p. 340. Examination of samples by H. R. Aldrich shows that the pre-Cambrian is really granite.

[h] C. R. Van Hise and C. K. Leith: Geology of the Lake Superior region. U. S. Geol. Survey, Mon. 52, 1911, p. 358; Samuel Weidman: Geology of north-central Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 16, 1907, pp. 518-520.

[i] Notes by Samuel Weidman. [j] Moses Strong: Op. cit., p. 520.

[k] Record by R. M. Bagg, Geology laboratory, Lawrence College, Appleton, Wis.

[l] T. C. Chamberlin: Geology of eastern Wisconsin. Geology of Wisconsin, vol. 2, 1877, pp. 156-157.

[m] Samuel Weidman and A. R. Schultz: Op. cit., p. 276.

[n] F. T. Thwaites: Sandstones of the Wisconsin coast of Lake Superior. Wisconsin Geol. and Nat. Hist. Survey, Bull. 25, 1912, p 60.

[o] Samuel Weidman and A. R. Schultz: Op. cit., p. 385. The record given on authority of Clements describes the rock at 1,000 feet as "hard siliceous shale," but it is more likely pre-Cambrian slate. Granite was encountered below 85 feet of this rock. Another version of this log in the files of the Geological Survey as copied from notes by W. C. Alden gives "red and gray shale" from 750 to 975 below which "sandy quartzite shale," probably slate, extended to 1,030. The rock from 1,030 to 1,060 was described in one version of the driller's log as "sand and light calcareous quartzite," possibly a marble, and in another as "quartz." All accounts agree that very hard crystalline rock was encountered at a depth of 1,060. It seems most likely from the record of well no. 3 that pre-Cambrian rock was encountered at 750 feet from the surface. A visit to the waterworks by the writer showed that this well is really No. 1, located east of No. 3, just across Rock River

Records obtained since map was drawn:

Augusta City (20 m. E. S. E. from 57): Elevation 968; depth to pre-C, 88; Elevation, pre-C, 880; rock, granite.

Oregon State Industrial School (7 m. S. from 23): Elevation 936; depth to pre-C, 850; Elevation, pre-C, 86; rock, rhyolite.

Augusta City (25 m. E. S. E. from 37): Elevation 968; depth to pre-C, 88; Elevation, pre-C, 880; rock, granite.
Oregon State Industrial School (7 m. S. from 23): Elevation 936; depth to pre-C, 850; Elevation, pre-C, 86; rock, rhyolite.

TABLE 2

Well records showing concealed pre-Cambrian rocks in and near Wisconsin which appear to be authentic reports.

Map number—city.	Owner or location.	Surface elevation.	Depth to pre-C.	Pre-Cambrian elevation.
45. Abbotsford	Railroad	1,422	80	1,342
46. Adams	Railroad	956	315	641[a]
47. Alma Center		967	424	543[b]
48. Appleton		720	822	—100
49. Arcadia		723	376	347
50. Ashippun	Railroad	854	443?	411?
51. Bangor	Railroad	753	400	353
52. Berlin		762	431	331[c]
53. Chilton	Malting company	877	885	—8
54. Combined Locks	Paper mill	655	790	—135
55. Dale		807	500	307
56. Durand	Court House	720	400	320
57. Eau Claire	Brewery	790	82	708
58. Elmore		980	1,248	—268[e]
59. Granton		1,112	40	1,072
60. Green Bay		590	910	—320
61. Jefferson	County farm	826	988	—162
62. Knapp	Oil test	970	630	340
63. Menomonee Falls	Sugar factory	835	1,175	—340[e]
64. Menomonie	City	810	400	410
65. Meridean		746	362	384
66. Mondovi		788	418	370
67. Oakwood Beach		585	917	—322
68. Oconto		590	596?	—6?
69. Platteville		900	1,714	—814
70. Portland	NW. ¼ 2, T. 9, R. 13 E.	830	695	135[e]
	NE. ¼ 29, T. 9, R. 13 E.	830	695	135[e]

Map number—city.	Owner or location.	Surface elevation.	Depth to pre-C.	Pre-Cambrian elevation.
71. Rice Lake		1,112	220	890
72. Richland Center		736	665	71
73. Ripon	SE. ¼ 14, T. 16, R. 14 E.	970	101	870[e]
74. Rosendale	SE. ¼ 14, T. 15, R. 15 E.	940	140	800[e]
	SW. ¼ 6, T. 15, R. 16 E.	920	102	820[e]
75. Rugby Junction		983	840	143
76. Shawano		822	142	680
77. Shenington		912	250	662[d]
78. Sparta		789	365	424
79. Weyauwega		779	212	567
80. Wild Rose		997	295	702[a]
81. Winneconne		754	426	328
82. Wonewoc	City	914	428	486
83. *Escanaba, Mich.*	Brewery	590	732	—142[f]
	C. & N. W. Ry. Co.	590	855	—265[g]
	Escanaba Manufacturing Co.	590	931	—341[f]
	Oil test	620	795	—175[h]
	Test hole, SW. ¼, NW. ¼ 8, T. 39, R. 21 W.	600?	780	—180[f]
84. *Brownsville, Minn.*		639	570	69[i]
85. *Lake City, Minn.*		712	820?	—108?[i]
86. *Red Wing, Minn.*		708	479	229[i]
87. *Wabasha, Minn.*		708	440	268[i]
88. *Winona, Minn.*		661	510	151[i]

[a] Record furnished by Chicago & Northwestern Ry. Co. [b] Record furnished by W. G. Kirchoffer.

[c] Samuel Weidman: Pre-Cambrian igneous rocks of Fox River valley, Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 3, 1898, p. 33.

[d] Record obtained by writer; sample of gneiss received January 20, 1931.

[e] W. C. Alden: Quaternary geology of southeastern Wisconsin. U. S. Geol. Survey, Prof. Paper 106, 1918, p. 71.

[f] R. C. Allen: Relative to an extension of the Menominee iron range. Michigan Geol. and Biol. Survey, Pub. 18, 1914, p. 163.

[g] R. A. Smith: Results of deep borings. Michigan Geol. and Biol. Survey, Pub. 24, 1917, pp. 214-215.

[h] R. B. Newcombe: Oil and gas development in Michigan. Michigan Geol. Survey, Pub. 37, 1928, p. 282.

[i] C. W. Hall and others: Geology and underground waters of southern Minnesota. U. S. Geol. Survey, Water-Supply Paper 256, 1911.

Other records from Samuel Weidman and A. R. Schultz: Underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915.

Geology

IGNEOUS ROCKS

As might be presumed from a comparison with the exposed pre-Cambrian area, the greater portion of the concealed rocks is igneous, and among them granite predominates. Basic rocks, particularly basalt, are not uncommon as is shown by the area of such rock under the city of Madison, as well as by isolated occurrences elsewhere. A tube of samples from the old artesian exploration at Kilbourn described by Lapham [7] was recently studied by the writer. This record (Table 3) shows a complex of

TABLE 3

Artesian exploration which penetrated igneous rocks, Kilbourn, Wisconsin. Samples in tube, Geological Museum, University of Wisconsin, examined by F. T. Thwaites

	Thickness feet	Depth feet
Cambrian:		
Sandstone, no samples	450	450
Pre-Cambrian:		
Basalt, weathered, greenish gray and pink	40	490
Basalt, decomposed	30	520
Basalt, pinkish gray, contains abundant shavings of native copper, apparently without connection with the rock; Lapham states that copper and silver were found through an 18-foot layer of exceedingly hard rock	50	570
Basalt, dark gray	20	590
Quartzite or vein quartz	10	600
Basalt, dark gray, slightly schistose	33	633
Granite and granite gneiss, pink and gray	366	999

basalt, granite, and gneiss to a total thickness of 549 feet. Drilling indicates that the coarse-grained granites of east central Wisconsin extend eastward under the Paleozoic rocks, for similar rock is found at Green Bay, Oshkosh, Kaukauna, and Casco Junction. The Portage exploration well found a rhyolite not dissimilar to that which occurs in exposures in the same general region and suggests that there is a considerable concealed area of rocks like those of the adjacent inliers. An interesting feldspathic rock was found in the Waupun well; it is probably a pegmatite. Gabbro has been found only at Whitehall. What appears to be an outcrop of a coarse grained red granite occurs in the northwest ¼, northeast ¼, section 10, township 14, range 6 east, Adams County. This exposure, only 10 by 25 feet in extent, shows marks apparently due to wind drift of sand up and down the gully in the deltaic

[7] I. A. Lapham: Ann. Rep. for 1874. Geology of Wisconsin, vol. 2, 1877, pp. 50-51.

35, 1915.
Samuel Weidman and A. R. Schultz: Underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull.

outwash plain in which it is situated. It is barely possible that this rock is a huge ice-rafted boulder.

METAMORPHOSED SEDIMENTARY ROCKS

General statement.—Although underlying a much smaller area than do the igneous and metamorphosed igneous rocks, the altered sedimentary rocks of the concealed pre-Cambrian offer a much more interesting problem. Some are extensions of areas long known at the surface and others are concealed throughout their extent. It is known from studies of the exposed pre-Cambrian that the areas of metamorphosed sediments can be divided into two general classes: (*a*) small isolated masses included in younger intrusive igneous rocks, and (*b*) large areas little affected by intrusions and in many places unconformable to the adjacent igneous rocks of greater age. Necedah Mound seems to be a good example of the first class and Baraboo Range of the second. Both classes appear to be of Huronian age. The metamorphosed sediments consist of quartzite, slate, iron formation or jasper, dolomite, and various schists.

The principal areas of such rocks are: (*a*) the Baraboo Range of Sauk and Columbia counties, a considerable part of which is exposed; (*b*) the Waterloo Range of Jefferson, Dodge, Fond du Lac, Sheboygan, Washington, Ozaukee, and Waukesha counties which is exposed only in the first two localities; (*c*) the entirely concealed Fond du Lac Range of Dodge, Fond du Lac, and Calumet counties; (*d*) what is probably a large area of quartzite west of Two Rivers in northern Manitowoc County; and scattered areas of quartzite at (*e*) Marinette, and (*f*) Barron, the latter probably an extension of the Barron quartzite of Barron, Rusk, and Sawyer counties. Besides the localities listed above there are a number of inliers of quartzite and iron formation whose buried extensions are for the most part unknown. These comprise: (*a*) North Bluff in Wood County, (*b*) Necedah Mound in Juneau County, (*c*) several mounds of iron formation near Black River Falls, and (*d*) Hamilton Mounds in Adams County. The last named locality, although not far from a main highway, remained unknown until 1929, when it was discovered by E. F. Bean, State Geologist, in the course of road material work.

Baraboo Range.—The Baraboo quartzite range with its associated slate, iron formation, and dolomite is too well known through mining and exploration[8] to demand extended description. Few of the results of drilling have been published, but for the purpose of the present paper it will suffice to say that no extension of the altered pre-Cambrian sediments

[8] Samuel Weidman: The Baraboo iron-bearing district. Wisconsin Geol. and Nat. Hist. Survey, Bull. 13, 1904.

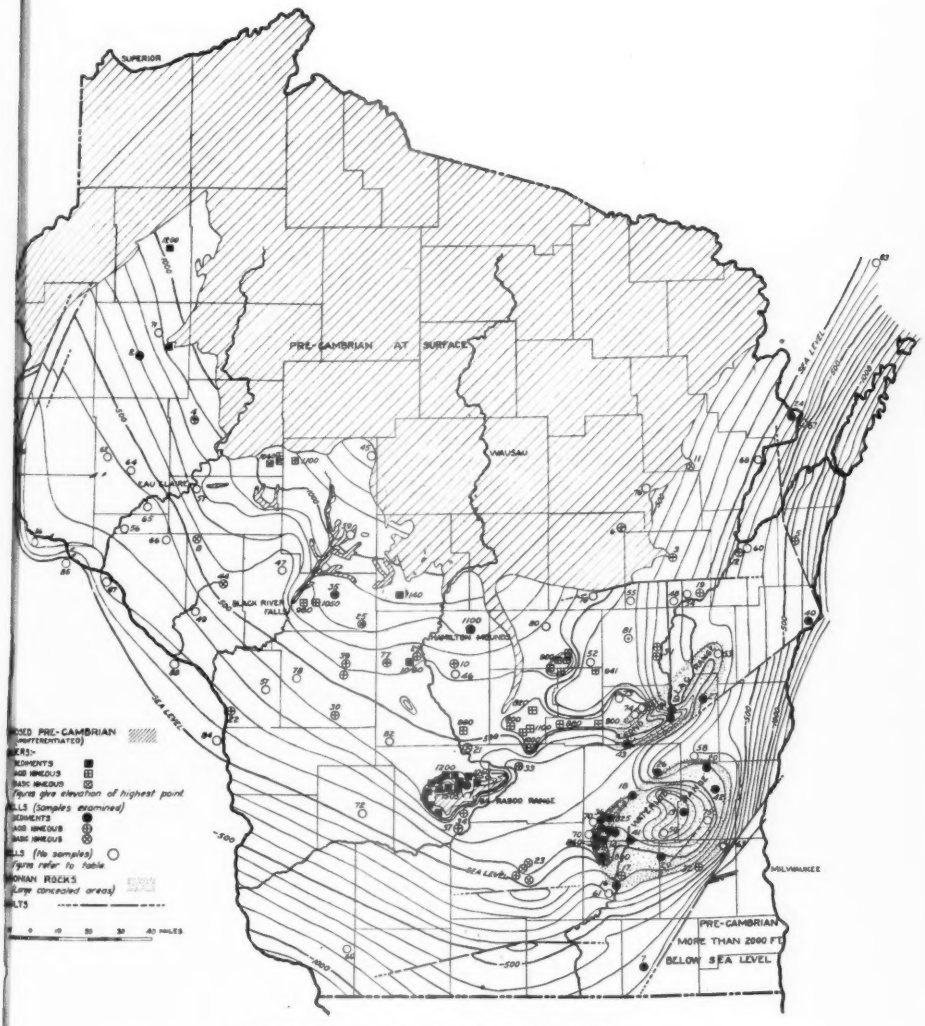

FIGURE 1.—*Buried pre-Cambrian of Wisconsin*

Contour interval 100 feet. See Tables 1 and 2. The probable extent of the Waterloo and Fond du Lac ranges of Huronian rocks is shown, but no attempt has been made to map the quartzite ranges discovered at other points. Most of the concealed pre-Cambrian is igneous. No attempt has been made to show the base of the Cambrian in the Lake Superior syncline near the Saint Croix River in northwestern Wisconsin.

has ever been found outside the main synclinal valley. The work of Jay (see page 720) did not add materially to our knowledge of the buried pre-Cambrian topography, for it was confined to the areas drilled for iron ore. Much still remains to be worked out in regard to pre-Cambrian physiography in this district, particularly in regard to the age of the gaps through the quartzite ranges and of the upland plains which bevel the layers of the folded quartzite.

Waterloo Range.—The Waterloo Range has been investigated by Chamberlin, Buell, Warner, and Alden.[9] A portion of the west and northwest sides of a syncline which plunges to the north of east is fairly well exposed. It does not seem too great a stretch of the imagination to extend this structure to include the definitely identified metamorphosed sediments found at Juneau, Jefferson, Mayville, Hartford (Table 4, page 732), and Kewaskum. Quartzite and other hard rocks far above the level at which such formations would be expected have been reported at West Bend, Rugby Junction, Menomonee Falls, Oconomowoc, and near Pewaukee. Within the elliptical area thus outlined on figure 1 the well at Jefferson Junction found granite and well number 3 at Watertown a cherty iron formation at first erroneously thought to be red shale. Well number 2 was at first reported to have struck granite, but the writer is convinced that what was termed "red shale" is more likely pre-Cambrian iron formation like that in the later well. Exploration holes found slate, schist, and dolomite between the Hubbleton outcrops and Watertown (Table 1, page 722). It would appear from the records of these holes that either the structure of this range is more complicated than that of the Baraboo district or the stratigraphic succession is somewhat different, for dolomite is found at Waterloo apparently below the iron formation. Pegmatite dikes are known at the surface and a well at Hartford penetrated a diabase dike.

Shortly before 1923 a well was drilled to a depth of 1,890 feet on the Etscheid farm southwest of Reeseville. The log of this interesting hole as given in Table 4 (page 732) is based on samples and on information furnished by the owner. The hole seems to have passed through the lower portion of the Waterloo quartzite into a complex of schist and gneiss. These rocks appear to be in part at least sediments altered by intrusions

[9] T. C. Chamberlin: Geology of eastern Wisconsin. Geology of Wisconsin, vol. 2, 1877, pp. 252-256. I. M. Buell: Geology of the Waterloo quartzite area. Wisconsin Acad. Sci., Trans., vol. 9, 1893, pp. 255-274. The boulder trains from the outcrops of the Waterloo quartzite. Wisconsin Acad. Sci., Trans., vol. 10, 1895, pp. 485-509. J. H. Warner: The Waterloo quartzite area of Wisconsin. Unpublished thesis, Library of University of Wisconsin, 1904. W. C. Alden: Quaternary geology of southeastern Wisconsin. U. S. Geol. Survey, Prof. Paper 106, 1918, pp. 62-70.

and shearing. The well was almost completely dry. Metallic copper was observed in several samples, but the driller, August Berkholtz, explained that this undoubtedly came from copper wire which was used to protect the wire drilling line from abrasion against the sides of the hole.

Fond du Lac Range.—The presence of metamorphic sedimentary rocks, presumably of Huronian age, has been definitely established at Fond du Lac through examination of samples (Table 4, page 732). These rocks comprise slate and quartzite and apparently were mistaken by well drillers for hard sandstone and shale of the Paleozoic. The areal extent of these rocks is little known and the hypothetical distribution shown in figure 1 (page 729) is merely a surmise. Quartzite has been reported at Mount Calvary and Chilton,[10] and Alden [11] reports several wells between Fond du Lac and Ripon which found hard rock at a comparatively shallow depth; this rock is probably quartzite. The report at Chilton is rendered plausible by the finding of quartzite pebbles in samples from one of the city wells. The well at the insane hospital in Waupun probably reached quartzite if a fragment given to the writer by the driller is authentic. This specimen had lain around the driller's house for several years before being given to the Survey. The position of the quartzite at Two Rivers along the postulated strike of the Fond du Lac Range makes it quite possible that it is part of the same structure.

Other quartzite areas.—Smith [12] reports quartzite in a deep well at Marinette. The writer at first interpreted cuttings from the Delavan well (Table 1, page 722) as quartzite, but later experience has led him to doubt the accuracy of this interpretation as well as the reliability of an early study of samples from a slow-drilling sandstone at North Prairie, which also resulted in the opinion that pre-Cambrian quartzite was reached. Less definite are reports of quartzite at Alma Center [13] and Wonewoc.[14] Well number 1 of the Chicago and Northwestern Railway at Ashippun is reported to have encountered 215 feet of "hard crystalline limestone" above 15 feet of "green shale and calcite crystals." [15] Samples were not seen, but the description of the lower stratum is so unlike the normal Black River rocks that it strongly suggests a pre-Cambrian marble, although

[10] Samuel Weidman and A. R. Schultz: The underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915, pp. 263, 340.

[11] W. C. Alden: Quaternary geology of southeastern Wisconsin. U. S. Geol. Survey, Prof. Paper 106, 1918, pp. 70-71.

[12] R. A. Smith: Deep well borings. Michigan Geol. Survey, Pub. 24, 1917, pp. 238-239.

[13] Unpublished record in files; one version gives "blue granite" at depth 424.

[14] Samuel Weidman and A. R. Schultz: The underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915, p. 392.

[15] Idem, p. 307.

found at a depth of only 443.3 feet. Well records collected by Gilbert Raasch in the study of the Mauston quardrangle suggest a possible buried quartzite ridge for several miles along the Lemonweir River between Mauston and New Lisbon. As no samples were seen, the slow drilling may be due to other causes than pre-Cambrian rock.

Black River Falls iron range.—Near Black River Falls several small knobs of lean iron formations and mica schist rise through the Cambrian sediments. These have been described by Irving and Hancock[16] and were investigated in 1916 by parties under the direction of E. F. Bean. Subsequent drilling found gneiss in most of the holes, all of which were near the known outcrop.

TABLE 4

Wells which strike metamorphosed sediments of probable Huronian age. Samples examined by F. T. Thwaites

City well, Hartford, Wisconsin, drilled in 1927

	Thickness feet	Depth feet
Old pit, no samples	66	66
Richmond:		
Shale, bluish gray, dolomitic; layers of dolomite, dark blue, shaly	214	280
Galena and Black River:		
Dolomite, gray and bluish gray	259	532
Pre-Cambrian:		
Quartzite, vitreous, white and very light pink	272	804
Quartzite, vitreous, pink and light gray	6	810
Quartzite, vitreous, light gray	450	1,260
Quartzite, micaceous, light gray	75	1,335
Quartzite, vitreous, light gray	35	1,370
Basalt, (diabase?) dark gray, probably a dike or sill	15	1,385
Quartzite, vitreous, pink and light gray	10	1,395
Quartzite, vitreous, light gray and pink	15	1,410

Deep well of Fond du Lac Water Company, Fond du Lac, Wisconsin

Drift, no samples	106	106
Galena and Black River:		
Dolomite, no samples	190	296
St. Peter:		
Sandstone, shaly at bottom and top	179	475
Trempealeau and Mazomanie:		
Shale, sandy, pink, dolomitic	50	525

[16] R. D. Irving: Geology of central Wisconsin. Geology of Wisconsin, vol. 2, 1877, pp. 493-500. E. T. Hancock: The geology of the area at Black River Falls, Wisconsin. Unpublished thesis, Library of the University of Wisconsin, 1901.

	Thickness feet	Depth feet
Dresbach:		
Sandstone	215	740
Pre-Cambrian:		
Quartzite, vitreous, gray, pink and brown	30	770
Slate, gray and pink	20	790
Slate, red	8	798
Quartzite and slate, gray and red	12	810
Slate, gray and red	165	975
Quartzite and slate, red and gray	77	1,052
Slate, dark gray, hard	48	1,100
Quartzite, vitreous, gray and pink	6	1,106

Galloway-West well number 1, Fond du Lac, Wisconsin

Drift	49	49
Galena and Black River:		
Dolomite, bluish gray and gray	171	220
St. Peter:		
Sandstone with chert conglomerate at base	110	330
Lower Magnesian:		
Dolomite, gray, cherty	80	410
Trempealeau:		
Shale, sandstone, and dolomite, mainly pink	30	440
Pre-Cambrian:		
Quartzite, vitreous, pink	30	470
Quartzite, vitreous, light gray (no samples 500-510)	40	510

Galloway-West well number 2, Fond du Lac, Wisconsin, 640 feet south-southeast of well number 1

Drift	65	65
Galena and Black River:		
Dolomite, gray and bluish gray	205	270
St. Peter:		
Sandstone with chert conglomerate and red shale at base	100	370
Lower Magnesian:		
Dolomite, light gray	25	395
Trempealeau:		
Dolomite, light gray and pink, sandy	15	410
Conglomerate, oolitic chert in coarse gray sandstone	5	415
Pre-Cambrian?		
Sandstone, light gray and pink, very hard, many quartz enlargements, and some dark gray slate	10	425

F. C. Etscheid well, near Reeseville, Wisconsin, southeast ¼, southwest ¼, section 1, township 9, range 13 east. Samples presented by Lee Canfield and August Berkholtz, and additional information given by owner

Drift, no samples, probably till; no water, 6-inch pipe	93	93

	Thickness feet	Depth feet
Pre-Cambrian:		
Quartzite, light gray, much muscovite; caved at 140, lined with 5-inch pipe, 5-inch hole below	150	200
Schist, chiefly muscovite	150	350
Gneiss, granitic, light pink, much muscovite and biotite	250	600
Quartzite, schistose, biotite, muscovite, quartz, feldspar; drilled 18 to 20 inches in 24 hours	100	700
No samples with depth marked; appears to be largely quartz and mica schist, micaceous quartzite, and gray feldspar; cave at 1,250 lined with 4¼-inch casing	550	1,250
Schist, hornblende, mica; 4¼-inch hole	350	1,600
Quartzite, light pink, schistose, much muscovite	100	1,700
Schist, hornblende, chlorite, sericite	50	1,750
Schist, or gneiss, biotite, muscovite, quartz, feldspar	50	1,800
Basalt, dark gray, chlorite, copper from drilling line	50	1,850
Gneiss, gray, granitic, chloritic	30	1,880
No sample, probably like last	10	1,890

Structure

General statement

At first sight it might seem that the structure of the concealed pre-Cambrian of Wisconsin would be impossible to determine unless oriented drill cores were taken, and this supposition is largely true. Nevertheless inferences with regard to the structure may be drawn from three sources: (*a*) structure in nearby exposed areas, (*b*) areal distribution of the concealed rocks, and (*c*) faults and folds along which post-Paleozoic movement has occurred. As the topography of the surface of the old rocks has affected the structure of the younger covering, inferences which indirectly suggest the structure of the concealed pre-Cambrian may be drawn from this phenomenon as well.

Relation to adjacent exposed structures

Throughout most of central Wisconsin a northeast strike is prominent. Farther west the iron formations at Black River Falls strike north of west, suggesting that the axes of folds are concentric around the central mass of pre-Cambrian in the Wisconsin geanticline. Such a conclusion seems to be confirmed by the structure of the Keweenawan in northwestern Wisconsin where the southwest strike in the Lake Superior basin swings around to the southwest until it becomes south near Saint Croix Falls. From these facts it is inferred that the prevailing strike beneath the Paleozoic cover in eastern Wisconsin is northeast like that of the Baraboo Range.

DISTRIBUTION OF CONCEALED ROCKS

If we extend the known outline of the exposed portion of the Waterloo Range to include the proved buried occurrences of quartzite and other altered sediments, a structure similar to the Baraboo Range, except that it is larger and strikes more to the north, is a fairly conservative conclusion. As at Baraboo, the details of the structure are undoubtedly more complex than the present knowledge of the major features would suggest (figure 1, page 729). The granite at Jefferson Junction suggests intrusive rocks. The granite at Pewaukee is probably stratigraphically below the quartzite. The cherty and jaspery quartzite at Mayville may

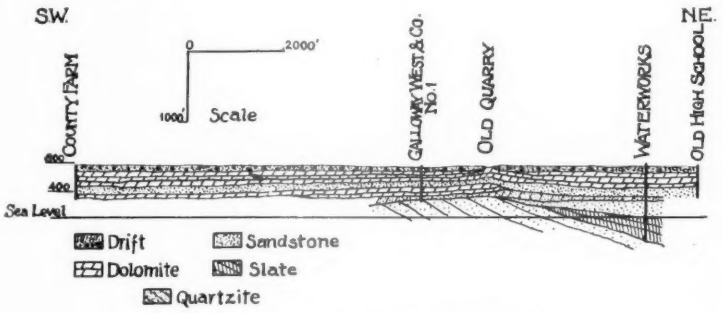

FIGURE 2.—*Section at Fond du Lac, Wisconsin*

Showing relation of Upper Cambrian and Huronian rocks. The anticline shown in the old quarry appears to be due, at least in part, to the buried quartzite ridge. It also coincides with the pinching out of the Lower Magnesian formation. See Table 4.

belong to an older series than the quartzite at Hartford and Waterloo. The Fond du Lac Range is so effectually concealed that its outline can only be vaguely surmised. A syncline similar to that of the Baraboo Range (figure 1, page 729) is postulated, and this syncline or another along the same strike probably accounts for the quartzite at Two Rivers. At Fond du Lac the finding of quartzite only in the Galloway-West well and of slate above the quartzite farther north at the waterworks strongly suggests a northerly dip (figure 2). A magnetic survey with the Hotchkiss superdip made by H. R. Aldrich on August 19, 1931, disclosed that the pre-Cambrian here strikes approximately north 60 degrees east.

STRUCTURE OF PALEOZOIC COVER

Although commonly supposed to be almost undisturbed, the Paleozoic rocks of Wisconsin are locally affected by faulting and folding. Such deformation almost certainly is the result of renewed movement along

planes of weakness in the underlying pre-Cambrian rocks. Faults have long been recognized at several localities: (*a*) east of New London,[17] (*b*) northwest of Janesville,[18] (*c*) south of Lake Waubesa, near Madison, (*d*) southwest of Two Rivers, (*e*) near Waukesha, (*f*) near Sturgeon Bay, (*g*) in northwestern Wisconsin in the vicinity of Lower Lake Saint Croix.[19] The writer has recently traced the first mentioned fault westward from New London for a long distance and eastward until it disappears under the drift near Greenleaf (figure 1, page 729). The absence of conglomerate in the Paleozoic rocks south of the granite knob which is located near New London[20] suggests depression to the south of this fault-line. An outcrop of granite discovered by the writer in the sand dunes east of Weyauwega seems to lie just north of this fault-line. The absence of sandstone in the wells in Weyauwega north of the river is probably also due to the same fault. The depression on the south side averages at least 100 feet. The eastward extension of the faults near Lake Waubesa and Janesville can only be surmised because of the heavy cover of drift.[21] It is not unlikely that the northern one extends east to the vicinity of Waukesha. It also seems possible that these faults are connected with the two lines of slight folding in southwestern Wisconsin discovered by Grant and Burchard.[22] At the better known localities each fault has a depression of about 100 feet on the north side.

The fault at Two Rivers, the largest thus far discovered in eastern Wisconsin, is demonstrated by two test wells drilled by the city. The first of these, located at the old high school, found hard rock at a depth of 1,800 feet. It seems probable that pre-Cambrian rocks were actually encountered above this depth as the yield of water proved to be small.

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[17] T. C. Chamberlin: Geology of eastern Wisconsin. Geology of Wisconsin, vol. 2, 1877, p. 280.

[18] Idem, p. 289.

[19] D. D. Owen: Report of a geological survey of Wisconsin, Iowa, and Minnesota. Map section 18, 1852. N. H. Winchell: Geology of Washington County. Geology of Minnesota, Final Rept., vol. 2, 1888, pp. 383-384. C. W. Hall and F. W. Sardeson: Paleozoic formations of southeastern Minnesota. Bull., Geol. Soc. Am., vol. 3, 1892, p. 344. Samuel Weidman and A. R. Schultz: The underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915, pp. 546-548. Eunice Peterson: Block-faulting in the Saint Croix valley. Jour. Geol., vol. 35, 1927, pp. 368-374. F. W. Sardeson: Block-faulting on the grand prairies? Pan-Am. Geologist, vol. 48, 1927, pp. 127-134. B. E. Karges: Faulting in the Paleozoic sediments near Hudson, Wisconsin. Unpublished thesis, Library of University of Wisconsin, 1930

[20] T. C. Chamberlin: Geology of eastern Wisconsin. Geology of Wisconsin, vol. 2, 1877, pp. 248-249.

[21] P. R. Wright: The geologic structure of the Cambrian of southeastern Wisconsin. Unpublished thesis, Library of the University of Wisconsin, 1930.

[22] U. S. Grant and E. F. Burchard: Geologic atlas of the United States, Lancaster Mineral Point folio (no. 145), 1907, p. 9.

W. G. Kirchoffer, who visited the city soon after this well was drilled, concluded: "From the statements of the driller it would appear that there was a buried knob of quartzite, rising up into the higher formation, in the vicinity of Two Rivers and that the drill, after penetrating some limestone and shale, had reached this knob." [23] A second hole (Table 5) was

TABLE 5

Log of test well at waterworks, Two Rivers, Wisconsin

	Thickness feet	Depth feet
Drift:		
Sand	32	32
Clay, red	68	100
Niagara:		
Dolomite, light gray, some white chert	670	770
Richmond:		
Shale, blue-gray, dolomitic, layers of blue-gray shaly dolomite	330	1,100
Galena-Black River:		
Dolomite, bluish gray and brownish gray	195	1,295
St. Peter (?):		
Sandstone, fine to medium grained, gray and yellow	45	1,340
Unknown, possibly Upper Keweenawan:		
Sandstone, fine grained, yellowish to brownish red, grains subangular	60	1,400
Sandstone, fine-grained, red, grains fairly well rounded	45	1,445
Sandstone, medium-grained, yellowish brown, grains angular	15	1,460
Sandstone, fine-grained, red, grains well rounded	15	1,475
Shale, sandy, reddish gray	15	1,490
Sandstone, fine-grained, yellowish red and gray, grains subangular	60	1,550
Sandstone, fine-grained, light red, grains angular	30	1,580
Sandstone, fine-grained, dark yellowish brown, grains rounded	15	1,595
Shale, sandy, dark red	15	1,610
Pre-Cambrian:		
Quartzite, vitreous, light gray to brown	30	1,640

drilled at the waterworks 1,750 feet east of the first test. The two wells show a displacement of approximately 375 feet in comparable horizons of the Paleozoic rocks.[24] It is possible that this displacement is a monoclinal fold similar to the one seen southwest of Sturgeon Bay. The Two Rivers displacement parallels the shore of Lake Michigan to the southwest and passes through some heavily drift-covered country to a point

[23] W. G. Kirchoffer: Unpublished manuscript.

[24] Samuel Weidman and A. R. Schultz: The underground and surface water supplies of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915, p. 432.

south of Fond du Lac which existing information does not locate exactly. The amount of movement certainly decreases toward the southwest. The northeast side of the great point north of Two Rivers is probably also related to a fault which trends west of north to the vicinity of Peshtigo. It may explain why a good well was drilled on one side of the river at Peshtigo and a nearly dry hole on the other. In the absence of a log of the poor well, no definite conclusion can be reached. This fault could not be definitely located in the course of work along the shore of Green Bay and doubtless decreases in displacement toward the north. It seems likely that the offset in the shore of Green Bay near Brussels is related to this line of movement.

A normal fault with strike north 47 degrees east and a downthrow of over 45 feet to the southeast is exposed in a quarry north of Waukesha. Compilation of all available well logs in and near the city indicates that other faults must occur, for in several wells some of the formations are abnormally thin and the elevations of contacts vary widely. These faults form two series, one of them parallel to the exposed fault and the other with a strike north 80 degrees east. Displacements reach a demonstrated maximum of 130 feet and form a series of horsts and grabens. This unusual amount of faulting may have some connection with the steep descent of the underlying pre-Cambrian toward the east (figure 1, page 729). A displacement is shown by a comparison of two of the quarries southwest of Sturgeon Bay and is exposed in the southeast ¼, northwest ¼, section 33, township 27, range 24 east. As the dip at the latter locality is 16 degrees to the southeast, the structure is clearly a monocline.

The existence of large faults in the vicinity of Lower Lake Saint Croix in northwestern Wisconsin, although denied by Sardeson, is now definitely proved. The major structures have a trend east of north with a maximum displacement of about 280 feet. A horst occurs at Hudson. Faulting is also known in exposures at Little Falls and near Osceola. In 1908 the writer discovered that part of the contact of the Paleozoic rocks with the pre-Cambrian trap rocks is along faults, a fact later confirmed by magnetic surveys under the direction of H. R. Aldrich. The faults of this district demonstrably affect the pre-Cambrian rocks although it can not at present be shown when the major part of the displacement occurred. It seems fair to suppose, however, that since the pre-Cambrian is so much more disturbed in this region than is the Paleozoic, most of the earth movements took place prior to the Upper Cambrian. The same conclusion seems logical for all of the above described faults.

RELATION BETWEEN STRUCTURE OF THE PALEOZOIC ROCKS AND THE PRE-CAMBRIAN FLOOR

Irregularities of the pre-Cambrian basement are commonly reflected in the structure of the overlying rocks. This relationship is ascribed to (*a*) initial dip along the old shore lines, and (*b*) differential compaction in the course of settling around a mass of hard rock. Around the largely exhumed Baraboo Range the Paleozoic sediments dip rather sharply away from the ancient islands, a fact which puzzled Irving [25] but which modern geologists have learned to expect. A better base map and more observations are needed before the details of this phenomenon can be disclosed. The extent of disturbance of the Paleozoic rocks above the Waterloo Range can not be observed in detail on account of the cover of drift, but Chamberlin [26] long ago noted disturbances at Hartford, where later drilling disclosed pre-Cambrian quartzite immediately below the Black River dolomite. It is also noticeable that the highest known elevation of the base of the Niagara dolomite in eastern Wisconsin is reached just northwest of Hartford.

In the vicinity of Fond du Lac the structure of the Paleozoic rocks is irregular. Several marked anticlines and synclines occur in both the Niagara and the Galena dolomites. Of these the one exposed in a stable yard just northwest of the city park has a strike of north 60 degrees west; it has been described by both Chamberlin and Alden.[27] The latter ascribed it to glacial pressure against an escarpment of dolomite. Its crest is marked by an open fissure and suggests recent movement under rather light load. Although probably altered by ice shove, the relation of this anticline to the surface of the underlying quartzite seems too close to be attributed to coincidence. The Saint Peter sandstone is about 90 feet higher in the Galloway-West well number 1 than in the old city well (table 4, page 732, and the former hole is not far from the axis of the fold (figure 2, page 735). The relation of the Two Rivers anticline to the eastward extension of the Fond du Lac Range is also very suggestive of settling over a mass of hard pre-Cambrian rocks. The position of the fault southwest of Two Rivers along the southeast side of the range is also too close for a coincidence. Southwest of Tomah there is a marked anticline which

[25] R. D. Irving: Geology of central Wisconsin. Geology of Wisconsin, vol. 2, 1877, pp. 536-539.

[26] T. C. Chamberlin: Geology of eastern Wisconsin. Geology of Wisconsin, vol. 2, 1877, p. 333.

[27] T. C. Chamberlin: Geology of eastern Wisconsin. Geology of Wisconsin, vol. 2, 1877, p. 310. W. C. Alden: Quaternary geology of southeastern Wisconisn. U. S. Geol. Survey, Prof. Paper 106, 1918, p. 207.

trends northeast. The new city well, located near the extension of the axis of this structure, found granite much closer to the surface than in the old well farther south (Table 1, page 722).

The facts outlined above point to the conclusion that most, if not all, of the local irregularities of structure that occur in great numbers throughout the State are related to the topography of the underlying pre-Cambrian. The most striking of these irregularities is Glover Bluff in northwestern Marquette County, which has been investigated by Alden, Ekern, and the writer.[28] Alden ascribed the disturbances to glacial shove, but this explanation was not regarded by the later investigators as an adequate cause for the observed facts. It was suggested by them that renewed movement of a pre-Cambrian graben might have caused the depression of the formations far below the expected level and produced faulting and folding.

The Red Clastic Series

In a considerable part of northwestern Wisconsin, and possibly in eastern Wisconsin as well, a thickness of a few feet to several hundred feet of red sandstones and shales intervenes between the recognized Paleozoic sediments and the underlying pre-Cambrian igneous and metamorphic rocks. These rocks are not known to outcrop in Wisconsin except in the Lake Superior basin. The quartzite of Barron, Rusk, and Sawyer counties may, however, prove to be their hardened equivalent, although lithologic character seems to ally it rather with the Huronian rocks. A number of investigators have studied the Barron quartzite and the concealed Red Clastic Series,[29] but their results are far from agreement. There is good reason to doubt that all the red rocks are of the same age, and it is certainly unwise to use color alone as a basis of correlation. Red shale and

[28] W. C. Alden: Quaternary geology of southeastern Wisconsin. U. S. Geol. Survey, Prof. Paper 106, 1918, pp. 207-208. G. L. Ekern and F. T. Thwaites: The Glover Bluff structure, a disturbed area in the Paleozoics of Wisconsin. Wisconsin Acad. Sci., Proc., vol. 25, 1930, pp. 89-97.

[29] T. C. Chamberlin: The quartzites of Barron and Chippewa counties. Geology of Wisconsin, vol. 4, 1882, pp. 573-581. N. H. Winchell: Natural gas in Minnesota. Minnesota Geol. Survey, Bull. 5, 1889, p. 25. A. D. Meeds: The Stillwater deep well. Minnesota Acad. Sci., Bull., vol. 3, 1891, pp. 274-277. C. E. Hall, O. E. Meinzer and M. L. Fuller: Geology and underground waters of southern Minnesota. U. S. Geol. Survey, Water-Supply Paper 256, 1911, pp. 32, 48, 366. F. T. Thwaites: Sandstones of the Wisconsin coast of Lake Superior. Wisconsin Geol. and Nat. Hist. Survey, Bull. 25, 1912, pp. 58-61. C. W. Hall: The red sandstone series of southeastern Minnesota (abstract). Science, n.s., vol. 27, 1908, p. 722. W. O. Hotchkiss, E. F. Bean and W. O. Wheelwright: Mineral land classification. Wisconsin Geol. and Nat. Hist. Survey, Bull. 44, 1915, pp. 35-45. C. R. Stauffer: Age of the red clastic series of Minnesota. Bull. Geol. Soc. Am., vol. 38, 1927, pp. 469-478.

sandstones are common in what is definitely known to be Upper Cambrian. Such red rocks extend at least as far south as Chicago and represent times when red material was washed from the old lands in such quantities that the organic matter of the sea bottom was insufficient to reduce it to lighter colors. Naturally such rocks would be sparingly fossiliferous. Stauffer has recently found Middle Cambrian fossils in well cuttings of red sandstone from central Minnesota and has suggested that the entire series of

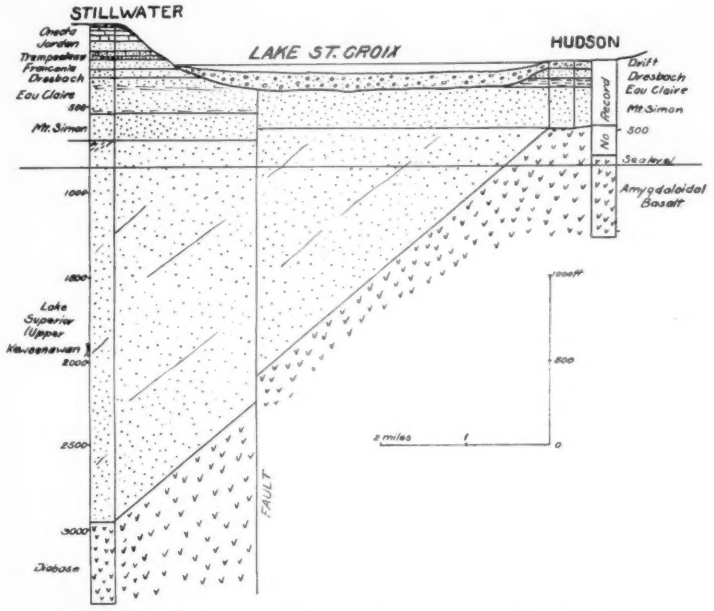

FIGURE 3.—*Section from Stillwater, Minnesota, to Hudson, Wisconsin*

Showing relation of proved Upper Cambrian formations to the red shales and sandstones found in the Stillwater boring. These rocks appear to be separated by an angular unconformity. The red rocks may be either earlier Cambrian or Keweenawan. The diabase and basalt are certainly Middle Keweenawan.

red sediments is of that age. If such is the case, an angular unconformity like that suggested in figure 3 may exist between the Upper Cambrian and the red sandstone. As pebbles of Barron quartzite are found in adjacent sandstones, for instance, in the Barron well, it is clear that this formation is considerably older and is unconformable below the Upper Cambrian. If the red clastics are classified as Keweenawan, this question

becomes involved with the age of the underlying lavas, a subject which has been debated for many years.[30] Suffice it to say that in drawing figure 1 (page 729) the red rocks below the lighter colored sandstones were ignored except at Stillwater, where it appears that they are closely related to the Keweenawan traps.

In eastern Wisconsin and northern Illinois[31] similar red rocks lie below the known Upper Cambrian and at Two Rivers (Table 5, page 737) in the horizon of the middle Ordovician. The rocks in the latter locality are markedly different from normal St. Peter sandstone and appear to be lacking in water. In the Field well near East Troy[32] 435 feet of ferruginous and presumably red sandstone was found at a depth of 1,765 feet. F. M. Gray, Jr., of the Gray-Milaeger Drilling Company, informed the writer that his late father, F. M. Gray, Sr., drilled a well at the county farm west of Milwaukee to a depth of over 3,000 feet which ended in red sandstone. Deep wells at Rockford, Illinois, only a few miles south of the Wisconsin line, encountered red sandstones at different stratigraphic horizons of the Upper Cambrian and suggest an unconformity. As well drillers have learned to avoid drilling far into these red rocks on account of salt water and few data are now coming in by which the question can be solved, for the present at least the red clastic series must remain an enigma.

Origin of the Surface of the pre-Cambrian

General statement

The pre-Cambrian area of Wisconsin is so deeply covered by glacial drift over most of its extent that little definite idea of its configuration can be obtained. Localities where little or no drift is present are: (*a*) Marathon County along Wisconsin River extending south into Wood County, (*b*) northern Oconto and Marinette counties, (*c*) Barron and Rusk counties in the area of Barron quartzite, and (*d*) along parts of the highland south of the Lake Superior basin. Three distinct classes of rock topography may be distinguished: (*a*) high hills and elongated ridges and valleys on tilted quartzite, iron formation, slate, and other

[30] C. K. Leith: Relation of the plane of unconformity at the base of the Cambrian to terrestrial deposition in late pre-Cambrian time. Cong. Geol. Internat., XIIme Sess., Compte Rendu, 1914, pp. 335-337.

[31] F. T. Thwaites: The Paleozoic rocks found in deep wells in Wisconsin and northern Illinois. Jour. Geol., vol. 31, 1923, pp. 555. Stratigraphy and geologic structure of northern Illinois. Illinois State Geol. Survey, Rep. of Investigations, No. 13, 1927.

[32] Samuel Weidman and A. R. Schultz: The underground and surface water supplies of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, 1915, p. 594.

altered sediments, and on tilted Keweenawan traps with interbedded sediments; (*b*) hills composed of diverse kinds of igneous rocks which vary in resistance to weathering and erosion; and (*c*) rolling to literally flat areas on massive rocks. The first class is represented in the iron ranges, the large isolated hills like the Baraboo Bluffs and Rib Hill, north of the Gogebic Range, and near Saint Croix Falls. The second class occurs in the Oconto-Marinette County area and the last is well developed in Wood County. Surfaces of these several types, some of which have a relief in excess of 500 feet, occur also beneath the Paleozoic cover.

Of necessity, the scattered data on which figure 1 (page 729) was based tend to exaggerate the evenness of the topography of the concealed pre-Cambrian. The major relief features of the concealed area are the Waterloo and Fond du Lac ranges heretofore described. Both of these rise several hundred feet above the average level of the hard rocks, and east of the Pewaukee well a drop of over 2,300 feet in the pre-Cambrian surface takes place in a few miles. Many mounds of igneous rocks which rise through the sediments in the Fox River valley are over 500 feet higher than the average of the surrounding pre-Cambrian. Truly flat areas, like that beneath Madison, are decidedly rare.

INTERPRETATION OF EROSIONAL HISTORY

Van Hise[33] first suggested that the surface of the exposed pre-Cambrian of central Wisconsin had been eroded to a baselevel or as now more commonly termed a peneplain. He thought this had been done during the erosion of the Paleozoic rocks and correlated the surface with a supposed peneplane in the younger rocks to the south. Later Weidman[34] demonstrated that the surface of the exposed pre-Cambrian slopes beneath the covering of Paleozoic rocks in the vicinity of Wisconsin (then Grand) Rapids, and thus proved that the peneplain is of pre-Cambrian age. This conclusion was later confirmed by Martin.[35] These authors stressed the flatness of the surface of the old rocks, the eroded folds, the deep-seated origin of most of the igneous rocks, and the presence of supposed pre-Cambrian residual soils. All these were taken to prove peneplanation by subaerial agencies. Although there can be little question of the propriety

[33] C. R. Van Hise: A central Wisconsin baselevel. Science, n. s., vol. 4, 1896, pp. 57-59.

[34] Samuel Weidman: The pre-Potsdam peneplain of the pre-Cambrian of north central Wisconsin. Jour. Geol., vol. 11, 1903, pp. 289-313.

[35] Lawrence Martin: The geology of the Lake Superior region, physical geography. U. S. Geol. Survey, Mon. 52, 1911, pp. 85-108. The physical geography of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, 1916, pp. 347-373.

of calling the surface of the pre-Cambrian, both exposed and concealed, a true peneplain, the writer wishes to point out that this surface is by no means as level and smooth everywhere as it is in some of the well-known exposures along the Black, Yellow and Wisconsin rivers. Irving,[36] who wrote before peneplains were in vogue, stated "the irregular surface of the crystalline rocks . . . may bring them up through to the surface at any point." And, "Near to this boundary line (the margin of the pre-Cambrian) it is not always possible to be sure that we have to deal with an isolated area, when we find a moundlike exposure of crystalline rocks, with sandstone showing in the vicinity at lower levels, on account of the intricate and somewhat indefinite nature of the boundary itself." The few really flat areas seem to have been developed on massive rocks.

Another question which arises is the extent to which marine planation affected these flat areas. It is true that conglomerate is not common in the basal Upper Cambrian. The lowest sediments are coarse sandstones with scattered pebbles, most of which are quartz, but wave wash might have removed most of the gravels from cut terraces to deeper water. Naturally exposures of low places in the pre-Cambrian surface are not common, and wells are not abundant enough to warrant the conclusion that no basal conglomerate exists where the Cambrian strata rest on the peneplain. Even around islands in the Cambrian sea, like the Baraboo Bluffs, conglomerate does not occur at all levels but seems rather to have been developed during times of quiescence when the sealevel remained the same for a long period of time and the waters were deep near shore. This subject will certainly bear much more thorough investigation than has been given to it in the past.

Much of the surface of the concealed pre-Cambrian, particularly where rocks of diverse character occur, was quite rugged before the burial under the Cambrian sediments. This is notably true in northwestern Wisconsin where the pre-Cambrian consists of Keweenawan lavas.[37] It seems unlikely that the extremely rough granite hills near Mountain, Oconto County, are wholly post-Cambrian in age, for those of the Fox River valley which project through the sediments are certainly pre-Cambrian monadnocks. On the other hand, it is clear that the discordance between the course of the Wisconsin River and the rock structure in the well-

[36] R. D. Irving: Geology of central Wisconsin. Geology of Wisconsin, vol. 2, 1877, pp. 490-491, 501.

[37] C. P. Berkey: Geology of the Saint Croix Dalles. Am. Geologist, vol. 20, 1897, pp. 345-383, vol. 21, 1898, pp. 139-155, 270-294. H. R. Aldrich: Unpublished surveys.

dissected area near Wausau is positive evidence of superposition [38] on a cover of Paleozoic rocks. The valleys of this district are thus certainly post-Cambrian in age and are markedly out of harmony with remnants of the old surface which forms the divides.

In the Baraboo Range youthful valleys due to superposition are easily distinguishable from the mature pre-Cambrian valleys, many of which contain remnants of the Paleozoic strata. At Weidman Falls in section 35, township 11, range 4 east there is an excellent example of superposition in an early stage. The highest parts of the range at an elevation of 1,470 feet are flats which bevel the folded strata. These are regarded by Trowbridge [39] as portions of the Dodgeville Peneplain, that is, as due to erosion during the removal of the Paleozoic cover. Martin [40] thought that this surface was developed in pre-Cambrian time, but the writer wishes to suggest a third explanation, namely marine planation during a still-stand of the land in the midst of the period of submergence. Such an explanation would account very well for such perfect flats on so insoluble and hard a rock, and for the presence of coarse boulder conglomerate on the edges of the summit flat. Moreover, chert and sandstone residuum is present on the upland in a clay soil presumably derived from decomposition of the Black River and Galena dolomites. These facts alone rule out the first named explanation. Smaller flats and benches at 1,240 and 1,100 feet are also associated with conglomerate.

THE WEATHERED SURFACE OF THE PRE-CAMBRIAN

On parts of the level portions of the basement rocks of Wisconsin the surface of the pre-Cambrian is weathered to a depth of many feet below the bottom of the sandstone (figure 4). Outcrops in the valleys of the Eau Claire (near the city of the same name), Black, and Wisconsin rivers which show this phenomenon have been described by Irving, Buckley, and Weidman.[41] The first two ascribed the alteration of the pre-Cambrian

[38] Samuel Weidman: The pre-Potsdam peneplain of the pre-Cambrian of north central Wisconsin. Jour. Geol., vol. 11, 1903, pp. 289-313. Geology of north-central Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 16, 1907, pp. 618-620.

[39] A. C. Trowbridge: The erosional history of the Driftless Area. Iowa Univ., Studies in Nat. Hist., vol. 9, No. 3, 1921, pp. 61, 64-65. The history of Devils Lake, Wisconsin. Jour. Geol., vol. 25, 1917, pp. 352-357.

[40] Lawrence Martin: The physical geography of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, 1916, p. 68.

[41] R. D. Irving: On kaolin in Wisconsin. Wisconsin Acad. Sci., Trans., vol. 2, 1876, pp. 3-30. Geology of central Wisconsin. Geology of Wisconsin, vol. 2, 1877, pp. 464-493. E. R. Buckley: Clays and clay industries of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 7, 1901, pp. 31-32, 217-231, 270-274. Samuel Weidman: The pre-Potsdam peneplain of the pre-Cambrian of north-central Wisconsin. Jour. Geol., vol. 11, 1903, pp. 289-313. Geology of north-central Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. 16, 1907, pp. 388-392.

rocks to waters which descend through the overlying sandstone and escape into the valleys under the present topographic conditions. Weidman rejected this explanation in favor of the idea that the kaolinitic clays are remnants of pre-Cambrian residual soil which escaped marine erosion during the encroachment of the Upper Cambrian sea. He presented no direct evidence to support this interpretation but states that since the underlying rocks had been eroded to a peneplain, there must have been a

FIGURE 4.—*Kaolinitic Clay derived from weathering of Gneiss beneath basal Upper Cambrian Sandstone at Nekoosa, Wisconsin*

The abrupt contact of the coarse, pebbly sandstone with the bleached clay is strongly suggestive of recent alteration by waters acidulated by passing through the marcasitic layers of the sandstone. The red zone in the gneiss shows at the bottom. Photograph by Hans Becker.

deep residual soil, some of which would have been preserved under the later sediments. Although the present writer has not made a thorough study of these clays and decomposed rocks, he desires to make certain suggestions as to their interpretation.

Weathering of the superficial pre-Cambrian rocks is not confined to marginal areas but has been observed in well cuttings from deeply buried portions of the peneplain. Among many such may be listed Friendship, Green Bay, Necedah, Kilbourn, and Madison. As is the case with the exposed areas of disintegrated pre-Cambrian, most, if not all, of the concealed occurrences are on rather flat portions of the old basement. A con-

siderable proportion of wells pass from the sandstones directly into fairly fresh pre-Cambrian rocks. A large proportion of the exposed clays at this horizon range in color from greenish gray to white; they grade down into decomposed red and yellowish brown rock and usually preserve traces of the structure of the unaltered rock. In a few places in the overlying sandstone the writer has noted masses of clay which suggest decomposed pebbles. The basal sandstone also contains pebbles of quartz over an inch in diameter; most of this sandstone is very coarse grained. In many places the lower beds of sandstone are heavily charged with pyrite or marcasite which is now undergoing alteration as a result of percolating oxygen-bearing waters.

Although the presence of altered pre-Cambrian at considerable depths below the present surface might seem conclusive evidence that there was much weathering of the old surface prior to the coming of the Upper Cambrian sea, the writer is far from satisfied on this point. Neither the light colors of the exposed clays nor the texture of the overlying sediments seems to favor the idea that all the weathering, at least near the outcrop, is pre-Cambrian. It seems plausible to suggest that waters acidulated by passing through the overlying sulphides of the basal sandstone are kaolinizing the underlying feldspathic rocks. Most of the deeply buried examples of weathering show red and yellow colors like those of the deeper zone in the outcrops. If alteration under present conditions of topography is an important factor in producing the exposed clays, then a large part of them must have been made chiefly in post-Wisconsin time, for the rivers did not assume their present courses until after the Middle Wisconsin glaciation. Judging from the amount of water passing through these rocks even in dry weather, and from the depth of leaching of dolomite pebbles in adjacent sandy drift of Middle Wisconsin age, this conclusion does not seem ill-founded.

Moreover, the old idea that a level peneplain would necessarily have a deep residual soil seems doubtful to the writer. As the relief of a region became less and less as a result of erosion, ground-water circulation would slow up, deep alteration of the bed rock would become less marked, the soil and disintegrated rock would be eroded, and in the final stages of peneplanation solid rock would lie not far below the surface. Reasoning thus it is apparent that deeply disintegrated pre-Cambrian rocks probably represent the tops of elevations rather than extensive lowlands. Furthermore it seems to the writer that much alteration of the basement rocks may have taken place since their burial, for in the Lake Superior district altered dikes and oxidized iron ores are known far below water

table. The waters which penetrate through the Upper Cambrian sandstones, the most porous parts of which are near the base, are saturated with calcium and magnesium bicarbonates. Therefore carbon dioxide is available for the alteration of the underlying feldspathic rocks by the breaking up of these substances. On the other hand, the basal Paleozoic sediments do not suggest cementation with secondary carbonates, for they contain little calcite or dolomite. It is difficult to tell whether or not the waters contain dissolved oxygen at a depth of several hundred feet from the surface, for when the pressure is released in bringing a sample to the top, much of the dissolved gas escapes. There is, however, little in the sandstones to cause extraction of oxygen. The writer can see no valid reason which absolutely demands a pre-Cambrian age for the alteration of the buried pre-Cambrian rocks.

SUMMARY OF ORIGIN OF PRE-CAMBRIAN SURFACE

Although the surface of the concealed pre-Cambrian of Wisconsin may be called a peneplain, it is evident that the relief is much greater than has been supposed by many. This relief is not confined to areas of quartzite and is not wholly due to later deformation when the great anticlinal arch of the state was formed. The weathered surface of the concealed pre-Cambrian is probably due only in small part to pre-Cambrian weathering and was chiefly caused by underground waters under essentially the present conditions.

Economic Geology

GENERAL STATEMENT

The economic resources of the buried pre-Cambrian comprise iron ore, copper, and kaolinitic clay. The iron ore and clay have been exploited in the past although there is now little or no production.

IRON ORE

Iron formations, presumably of Huronian age, have been discovered at Baraboo, Black River Falls, Watertown, Fond du Lac, and Mayville. Intensive exploration and some mining were carried out in the first named district, but have now ceased entirely.[42] A little exploration drilling has been done at Black River Falls, Waterloo, and Necedah without any success. Mining was discontinued at Baraboo after the World War because the comparatively small and low-grade ore deposits would not bear the

[42] Samuel Weidman: The Baraboo iron-bearing district. Wisconsin Geol. and Nat. Hist. Survey, Bull. 13, 1904.

enormous expense of pumping operations. Some of the mines are reported to have yielded over 7,000 gallons of water per minute. The porous cover of sand, sandy glacial drift, and sandstone over the ore bodies led to the return of much of the water to the workings in an endless cycle. It is clear that under present economic conditions mining is not feasible in this district although it is reported that there are considerable reserves of ore.

The Waterloo exploration failed to discover any iron formation because the options were taken under three assumptions: (*a*) the easternmost exposures of quartzite represent the top of the formation, (*b*) the dip shown in these exposures remains constant to great depths and for a long distance to the east, and (*c*) the formations have the same thickness and stratigraphic relations as at Baraboo. Three holes were drilled in a narrow belt along the strike and no attempt was made to obtain a wide cross-section. Later the writer identified iron formation in a city well at Watertown (Table 1, page 722). Although this occurrence proves that an iron formation exists, it is much farther east and under far heavier cover than was originally hoped for. The ferruginous slate found in the old city well in Fond du Lac is far too lean to encourage exploration. Such is also the case at Mayville. The Necedah exploration found only igneous rocks (see Table 1, page 722). As drilling near Black River Falls and Pray was not followed by mining, it seems clear that merchantable ore was not discovered in quantity. At all other places than the Black River Falls district the depth of cover is excessive and serious water trouble would be inevitable in mining. In the Waterloo Range more than 700 feet of water-bearing sandstone and drift overlie the iron formation, and even if a shaft could be sunk to such a depth, caving which would let in an enormous amount of water would surely follow any attempt to remove large quantities of ore. Development of such deeply buried ores is apparently out of the question under any market conditions which can now be foreseen.

COPPER

Supposed copper discoveries which have come to the notice of the writer are those at Kilbourn and Reeseville. Although the former has been known for many years (see Table 1, page 722), it has never attracted any exploration. The samples from Kilbourn are available only in a small tube and it is possible that the copper was introduced by the hand of man. The Reeseville copper certainly came from copper wire wrapped on the drilling line.

CLAY

The kaolinitic clays of the weathered surface of the pre-Cambrian were once exploited on a considerable scale for brick, but so far as the writer is aware all operations have ceased.

SUMMARY OF ECONOMIC GEOLOGY

The difficulty first of finding and then of mining ores in the concealed pre-Cambrian far from the margin of the Paleozoic rocks is so great that development of even the known deposits will almost certainly be the task of future generations. There seems little chance of financial success in the time of those now living.

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ORDOVICIAN SECTIONS OF GREAT BRITAIN AND THEIR AMERICAN EQUIVALENTS[1]

BY RICHARD M. FIELD

(Read before the Geological Society, December 31, 1930)

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HISTORY OF INVESTIGATIONS

The type sections of the Ordovician, as defined by Charles Lapworth, are in Wales and Shropshire. The system was divided by Lapworth into three series: the Arenig, the Llandeilo, and the Bala. These three series are found nearly complete near Shelve in Shropshire. There has been considerable confusion in the use of the terms Llandeilo and Bala, largely owing to attempted correlation with beds of similar age in the Lake District. Professor Sedgwick referred all the formations above the Arenig to the Bala group; but according to Professor Marr the Llandeilo series of Murchison was subsequently used in the sense of the lower Bala of Sedgwick; the middle Bala was regarded as the Caradoc series; and Ashgillian has been proposed for the upper Bala. It is rather a curious circumstance that the Bala, under the above classification, becomes more nearly the equivalent of Ulrich's Ordovician, since Ulrich would correlate the subjacent Arenig with his upper Canadian.

The story is well known of how Lapworth, through his splendid work at Dobbs Linn, near Moffat, discovered the great correlation value of graptolites, and how he used these index fossils to unravel the intricacies of the Welsh and Shropshire sections. It is only near Girvan, in the Stinchar Valley section, that the graptolites appear to have led him seriously astray, and that was because of a structural rather than a paleon-

[1] Manuscript received by the Secretary of the Society March 16, 1931.

tological problem. Since Lapworth's time, there has been a tendency to divide the British lower Paleozoic faunas into the "shelly facies" and the "graptolite facies." The majority of the British geologists consider the shelly facies to be neritic and the graptolite facies bathyal. The bathyal origin of the American Ordovician graptolite shales has not been proved according to many American geologists. American geologists were generally given to understand that, with few exceptions, the fossils of the British shelly facies were too poorly preserved to be worth much for correlation purposes. Further, the formations recognized as Ordovician by the British contained very little actual limestone, except at Llandeilo and Bala, although many of the beds are calcareous. Most of the type Ordovician formations are ashes, grits, coarse sandstones, mud rocks, or shales. On the other hand, the type sections of the Ordovician in the eastern United States contain a much higher proportion of abundantly fossiliferous limestones, especially in the Appalachian Valley.

It is only since 1922 that the British have made any serious attempt to study the shelly facies of the Ordovician, and even now such studies are few. Mr. B. B. Bancroft, of Blakeney, Gloucestershire, has been working for several years on the Ony Brook section, and has made an excellent collection of trilobites and brachiopods. He has subsequently extended his researches to other areas in Wales. It is interesting to note, however, that with one or two exceptions the trilobites are different from ours; and the brachiopods (which are well preserved—showing both interior and exterior casts) represent not only different species, but, in many cases, different genera from those found in the Ordovician of the United States. One possible exception may be a Heterorthis similar to one in the Trenton of Kentucky.

At this point in my communication I shall discuss the recent history of the problem of the correlation of the British Ordovician and its American equivalents, for I feel that in this way I can best call to your attention, or at least remind you of, the principal difficulties in international correlations. As will be seen, these difficulties are imaginary as well as real. While they are sometimes the result of national pride, and usually take the form of an ultraconservative attitude to the introduction of foreign terms, or the desire to introduce new systems into the so-called standard time scale, the difficulties are largely due to the lack of a common knowledge of technique and field methods and other valuable considerations seldom discussed in papers on correlation. Ulrich's proposal to erect two new periods, the Ozarkian and the Canadian, increases the difficulty in using physical data for the delimitation of systems in widely

separated areas. The time has not yet come when the history of the earth, as disclosed by the sedimentary and paleontological record, can be properly arranged in a series of geological periods. The formations remain the important working units, and the facies present the interesting and exciting problems in stratigraphy. The purely structural evidence of unconformities and even important orogenies are too often masked by subsequent deformations, especially overthrusts, and the facies [2] often suggest the former geographies as well as the very nature of the deformations of the land masses and the character and direction of the forces involved.

The Beekmantown Problem

After a visit to the Northwest Highlands of Scotland, Doctor Grabau reported to the Geological Society of America in 1916 that he believed that the greater part of the Durness limestones were Beekmantown and not Cambrian as classified by Peach and Horn. I visited the Highlands first in 1922, and was immediately struck with the similarity between the Durness group and the Beekmantown of eastern North America. This holds true not only for the fossils (including algal reefs, not yet described) but also for the lithology, hence for the facies as a whole. In 1927 I revisited the section in company with Doctors Ulrich and Resser, of the United States National Museum. Doctor Ulrich was able to identify the fossiliferous beds of the Durness as middle (*Lecanospira*) and upper (*Hormotoma gracilens*) Canadian, both from fossils collected in the field and from examination of specimens in the Museum at Edinburgh. Regardless of the period significance, we have in the Durness-Beekmantown facies one of the closest intercontinental correlations in the lower Paleozoic. Further, the *Lecanospira* beds have the greatest known geographic distribution of any known lower Paleozoic facies, and their stratigraphic position can be very clearly determined in the Appalachian Valley. In 1929 I returned to the Durness section with Prof. O. T. Jones, now Woodwardian Professor of Geology at Cambridge. Jones was very much struck with the evidence, having had an excellent opportunity to study the Beekmantown in 1928.

In the last compilation of the geology of the Scottish Highlands ("Chapters on the Geology of Scotland," edited by MacGregor), we find the following statements:

(1) "The Lower Cambrian fauna of the North-West Highlands, distinguished by the genus *Olenellus* and its associates, is almost identical in character with

[2] By facies is meant the sum total of the lithologic and organic character of the formations or their units.

that of the Georgian terrane of the western life-province of North America, and essentially different from the Lower Cambrian fauna of Wales and the rest of Europe.

(2) "No forms characteristic of the Middle Cambrian division either of Europe or North America have as yet been found in the North-West Highlands, but this division may be represented by the unfossiliferous dolomites and limestones of the Ghrudaidh, Eilean Dubh, and the lower part of the Sailmhor groups.

(3) "The fossiliferous bands of the Sailmhor group may be the equivalents of the lower part of the Upper Cambrian formations.

(4) "The Balnakiel and Croisaphuill groups of the Durness dolomite and limestone contain a typical development of the molluscan fauna of the Beekmantown limestone, appearing in the eastern life-province of North America, which is regarded by most American geologists as of Lower Ordovician age. But, as the Beekmantown limestone in Newfoundland is overlain by shales with Arenig graptolites, it follows, in accordance with British classification, that these represent at least the Tremadoc strata of Wales, if not part of the Lingula Flags of that region.

(5) "The highest subdivision of the Durness limestone (Durine) has not yielded fossils of zonal value, and the members of this group are not overlain in normal sequence by graptolite-bearing shale or other sediments."

So we see, according to the last two paragraphs, that MacGregor, feeling that he can not correlate the Durness with any part of the British post-Cambrian or pre-Silurian formations, prefers to put the Durness in the upper Cambrian and to consider it as of the same age as the Tremadoc and Lingula Flags of Wales. On this line of reasoning we, in turn, would be forced to put the Tremadoc in the Canadian of Ulrich or well above our upper Cambrian, if Ulrich's Ozarkian is recognized, and thus rob Adam Sedgwick of some of his Cambrian. The really important mater is not the period to which these formations belong, but the fact that they represent different facies, and as such give us fundamental data regarding the paleogeography of the lower Paleozoic. Further, the shaly graptolite phase, equivalent to the Durness shelly carbonate facies, either has not been recognized or will not be hunted for by the British. So far, there appear to be no formations of undoubted Ozarkian age in Great Britain, but this may be because the particular facies has not yet been recognized.

The Chazy Problem

In 1928 it was arranged by the Princeton Summer School of Geology for Prof. O. T. Jones, then head of the Department of Geology at Manchester University, to visit the post-Cambrian and pre-Silurian formations of the Appalachian Valley. Professor Jones, Dr. Marcus Goldman,

and I, guided by Doctor Ulrich and Doctor Charles Butts, examined the type sections between central Pennsylvania and Bristol, Tennessee. Special attention was paid to the formations in the Canadian and the Chazy. In 1929 the Summer School, through Professor Jones, arranged for excursions in the lower Paleozoic of England, Wales, and Scotland. The American members of the party are deeply indebted to Professor Jones for organizing and leading the British field trip, and to the late Lord Melchett for his generosity in financing the entire cost of our transportation during the six weeks of extensive travel in Scotland, England, and Wales.

Just before the American party landed, Professor Jones made the discovery that the Stinchar limestone or "streaky bacon" was remarkably like the Lenoir of the Stones River of the southern Appalachians. This discovery was purposely kept secret from Doctor Ulrich in order that we might have his unbiased opinion when he examined the Stinchar Valley section personally. When Doctor Ulrich did examine the section later in company with Professor Jones and the rest of the party, he suggested that the Stinchar was the same facies as the Lenoir and that the beds overlying the Stinchar, the Glenkiln and Balaclatchie, correlate with portions of the upper Chazy or Blount. We were all very much puzzled, however, as to why Lapworth's description of the Stinchar fossils should include certain species which we were unable to find in the Stinchar Valley section, and which had distinctly American Silurian aspects. This difficulty was fortunately solved when during a visit to the Craighead Quarry, a short distance away, it was discovered that the Craighead limestone contained the "Silurian" fossils in question and was overlain by shales containing Ordovician graptolites. Unfortunately, Lapworth had failed to recognize that the contact between the limestones and the overlying shales was an overthrust, and he took the Craighead limestone fauna to be of the same age as the Stinchar limestone which is overlain by similar graptolite shales. Since the collecting was better in the Craighead formation than in the Stinchar limestone his faunal lists show a mixture of typical lower Chazy and upper "Silurian" forms. It would have been impossible for Lapworth to have dated the Stinchar according to the American sections, as the southern Appalachian Chazy had not yet been worked out and described. It is particularly significant that the Craighead "Silurian" is unlike any other known British Silurian facies, but shows American faunal characteristics, especially as to the corals. The coastal section near Girvan is quite a different facies from that of equivalent age in the Appalachian Valley. The beds of the coastal section

do, however, have a very close similarity with those of northeastern Newfoundland. The Stinchar Valley problem has been discussed by Doctor Ulrich, but is somewhat hidden under the title of the "Ordovician Trilobites of the Family Telephidæ and Concerned Stratigraphic Correlations." [3]

We now see that in North Scotland and the Scottish Lowlands—in other words, outside of the type areas of the Ordovician—exist certain equivalents of the American post-Ozarkian and the pre-Silurian formations; the Northwest Highlands exhibit appreciable elements of the northern Appalachian Beekmantown facies, and the Southwest Lowlands at least one formation typical of the southern Appalachian Chazy. The interest is still further heightened by the fact that only a short distance from the Stinchar Valley section exists a facies very similar if not identical with the Ordovician of Notre Dame Bay of northeastern Newfoundland. It is here, therefore, in the neighborhood of Girvan, that we have the American and British Ordovician facies in close proximity. We await with much interest Professor Schuchert's publication of the faunas of western Newfoundland and a comparison with the results of Princeton work in the northeast and central parts of that island, to be presented shortly by Dr. A. K. Snelgrove. It seems probable that Newfoundland will reveal a juxtaposition of American and British Ordovician somewhat similar to that in the Southwest Lowlands of Scotland.

The Trenton Problem

So far the American Trenton facies has not been discovered in Great Britain. I believe that rocks of approximately the same age undoubtedly exist in the shelly facies of Shropshire, as best exposed in the Caradoc of the Ony Brook section, and that certain of our early and late Trenton stocks are of British descent. It seems clear now that it will be very difficult, if not impossible, to make a direct correlation between the type Ordovician sections of Great Britain and those of the eastern United States; and the best that can be expected is the similarity of a few species.

In 1918, I reworked the Trenton of central Pennsylvania, and proposed that it be subdivided into the Salona and Coburn. My reasons for doing so were as follows: The Parastrophia zone, which is basal Trenton in New York State, occurs well up in the Trenton sections of central Pennsylvania. Between the Parastrophia zone and the top of the Black River (*i. e.*, in the Salona) occur 136 + feet of beds which, while they

[3] Proc. U. S. Nat. Mus., vol. 76, art. 21, 1930, pp. 1-100, pls. 1-8.

contain a number of typical Trenton fossils, present quite a different lithology from the beds above the Parastrophia zone (*i.e.,* Coburn). Further, these lower beds are characterized by the unique presence of *Brongiartella trentonensis* which Doctor Whitcomb has shown to be very closely related to *Homalonotus bisulcatus* from the upper Longvillian or Marshbrookian of the Caradoc of the Ony Brook section. None of the brachiopods of the Salona are particularly similar to those in the Caradoc, and the Trinuclidae have been shown by Doctor Bancroft and Doctor Whitcomb to be quite different. We have, therefore, in *B. trentonensis,* a single migrant from Shropshire which occurs only in central Pennsylvania. It probably migrated more rapidly than the Trinuclidae, and suggests that the basal beds of the central Pennsylvania Trenton may be homotaxial with the Caradoc, and that the typical New York Trenton is absent in Great Britain, but may be represented by homotaxial beds in the upper Caradoc.

I believe that the time has not yet come when either the United States or Great Britain can claim to have the most complete record of the Ordovician, or the most typical one. Further, both countries have more in common than had been fully appreciated. For what has been recently accomplished in matching the American Ordovician record with that of Great Britain, we have principally to thank Professor Jones and Doctor Ulrich.

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GEOLOGY OF THE BAHAMAS[1]

BY RICHARD M. FIELD AND COLLABORATORS

(Read before the Geological Society December 30, 1930

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HISTORY OF THE INVESTIGATIONS

The region designated as the Bahamas is shown on figure 1. That portion of the region which will be discussed in this paper may be termed the "Bahama Block," comprising Andros Island and the Great Bahama Bank. The particularly significant borders of the Bahama Block are the Santaren Channel on the west, and the tongue of the ocean on the east. The general position of this region in relation to the Florida coast is shown on figure 2. A number of scientists have visited this region, including, however, a relatively small number of geologists. For the sake of brevity, the writer has not attempted to present in this paper a summary of the previous geological investigations; only the recent and most significant papers are referred to in the text.

The writer's interest in the Bahamas was first aroused by Dr. Alfred G. Mayor during a visit to the Marine Biological Laboratory at Tortugas in 1918.[2] It was not until 1927 that the writer had an opportunity to visit the Bahamas. This preliminary trip was followed in 1928 by an oceanological survey with the cooperation of the Buffalo Society of Nat-

[1] Manuscript received by the Secretary of the Society April 10, 1931.

[2] R. M. Field: Investigations regarding the calcium carbonate oozes at Tortugas, and the beach rock at Loggerhead Key. Year Book No. 18 Carnegie Inst. Washington (for 1919), pp. 197, 198.

ural Sciences. The results of these two preliminary expeditions suggested the advisability of a more comprehensive study of the region, the outstanding problem being *the relation of the stability of the Bahama Block*

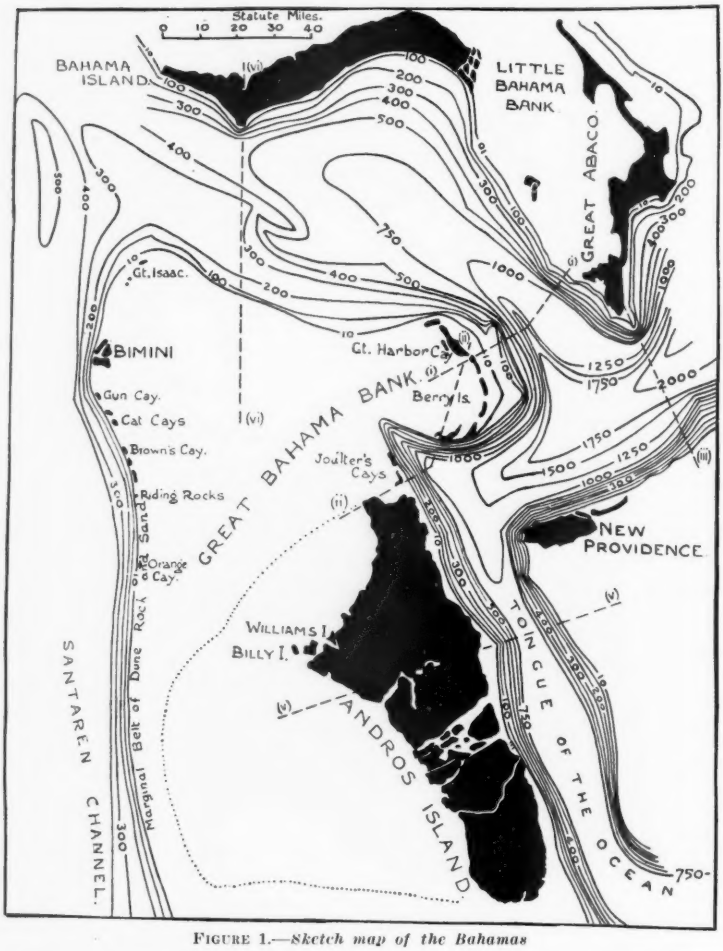


FIGURE 1.—*Sketch map of the Bahamas*

Prepared by Mr. Maurice Black. The Great Bahama Bank is covered with from 2 to 3 fathoms of sea water having approximately normal salinity. The Roman numerals designate profiles which are being published in another paper by Mr. Black. The dotted line shows the westward boundary of the maximum deposition of "drewite" or fine-grained calcium carbonate mud.

to the origin, migration, and alteration of the sediments which mantle its surface. After two years of consultation here and abroad, it was decided to lay out a three years' program for research in the Bahama and contiguous areas in the British West Indies. The first year's program has been completed by an expedition bearing the title "International Expedition to the Bahamas." The scientific staff of the expedition was as

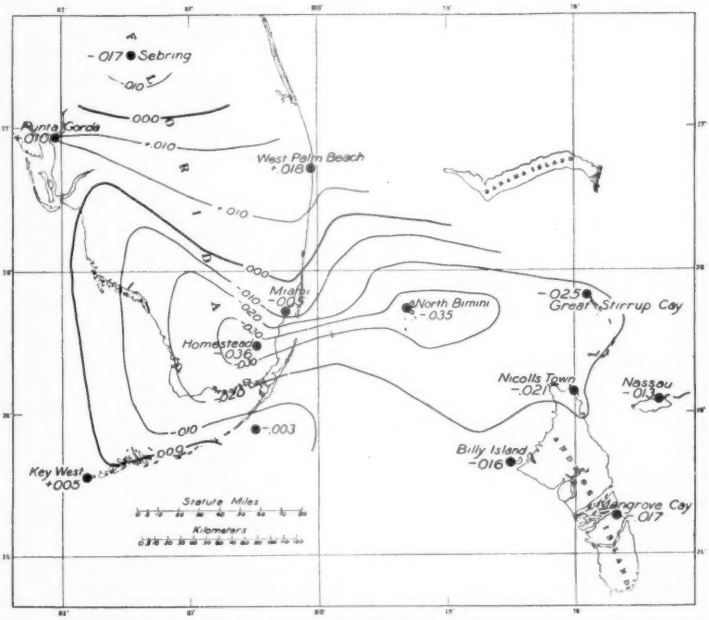


FIGURE 2.—*Showing the stations at which gravity was determined during the expedition, and the relation of these stations to those previously determined in Florida*

The seven stations made during the International Expedition are: Miami, North Bimini, Great Stirrup Cay, Nicolls Town, Nassau, Billy Island, Mangrove Cay.

follows: Hugh E. Matheson, of Coconut Grove, Miami, Florida—in charge of navigation; Joseph P. Lushene, of the United States Coast and Geodetic Survey, under the direction of Dr. William Bowie, Chief of the Division of Geodesy—in charge of gravity stations; Ernest Dixon, H. M. S. Geological Survey, and Dr. Richard M. Field—in charge of sedimentation and tectonics; Maurice Black, Commonwealth Fellow in Geology at Princeton University, and Fellow of Trinity College, Cambridge—in charge of the geology of Andros Island; Dr. Ulric Dahlgren of the De-

partment of Biology of Princeton University, and Dr. Roy Miner, Curator of Marine Invertebrates of the American Museum of Natural History—in charge of Invertebrate Ecology; Dr. Charles Fish, director of the Buffalo Museum of Science—in charge of Oceanology; Dr. Werner Bavendamm, of the Deutsche Forschungsgemeinschaft—in charge of microbiology.

The writer is deeply indebted to Dr. S. A. Waksman, of the New Jersey Agricultural Experiment Station, for his advice in planning the microbiological work and also for his personal help and the use of his laboratories and staff in the analysis of the materials collected by Doctor Bavendamm. The writer is also indebted to Dr. N. A. Cobb, of the Bureau of Plant Industry, Washington, D. C., for his analysis of the nematode material. The writer is particularly indebted to Captain R. S. Patton, Director of the United States Coast and Geodetic Survey, for the loan of instruments and the services of his staff. All the members of the scientific staff of the expedition wish to express their gratitude to Hugh E. Matheson for placing his yachts, their crews, and himself unreservedly at the disposal of the expedition, and also for his generosity in covering the entire expense of the oceanographic part of the expedition. Mr. Matheson's knowledge of the region and his ability as a navigator were the principal factors in the success of the expedition.

The field work started January 1, and ended April 15, 1930. Particular attention was paid to the following investigations: (1) Gravity measurements, (2) oceanology, (3) character of the sediments on the Bahama Banks, (4) marine ecology, (5) microbiology, and (6) geology of Andros Island. The investigation of this region is far from completed, but new information has adready been obtained, some of which is contrary to the opinions of previous investigators. The writer feels that the new data should be of particular interest to those concerned with geotectonics and problems in marine geology. Furthermore, the investigations have a direct bearing upon the possible source of fine-grained carbonate deposits such as those that form an important element of the Lower Paleozoic formations of the Appalachian Valley, parts of the British Lower Carboniferous of Yorkshire, and certain Cretaceous and Tertiary deposits.

Gravity Data

Although a number of gravity measurements have been made on United States territory in the West Indies, no such measurements have been made in the British West Indies. In order, therefore, to complete this gap in the general gravity data of the West Indian region, as well as to determine whether or not the Bahama Block was in isostatic equilibrium,

the Director of the United States Coast and Geodetic Survey, with the approval of the British authorities, responded favorably to the request of Dr. William Bowie and the writer that gravity be determined at the following localities: Miami, North Bimini, Great Stirrup Cay, Nicolls Town, Nassau, Billy Island, and Mangrove Cay (see figure 2). The observations were made by Joseph P. Lushene, an engineer of the United States Coast and Geodetic Survey and an expert in pendulum work plate 21, figure 4). The data secured by Mr. Lushene were computed and adjusted, as shown on the table, page 764, in the Washington office under the direction of Doctor Bowie. On figure 2 are shown the isostatic anomalies for the Bahama stations, as well as for six stations in southern Florida, and one station to the southeastward of the Florida Keys at which observations were made by Dr. F. A. Vening Meinesz in a submarine of the United States Navy in 1928. The sketch shows lines, which theoretically should have isostatic anomalies of the same magniture. According to Doctor Bowie:

"Undoubtedly, if there were additional gravity stations established in southern Florida, on the Bahamas, and in the waters surrounding the Bahama Bank, the curves shown on the sketch would be quite different; but the curves, as they are, give a fair idea of the areas for which there are anomalies of certain magnitudes. The most striking feature of the anomalies on the Bahamas is the fact that each one of them is negative. A large majority of the island stations of the world have positive isostatic gravity anomalies. As most of these islands are formed of igneous rock (where gravity has been determined) this is thought to be the reason for their positive anomalies. It seems to be reasonably certain from the evidence of the gravity data that the Great Bahama Bank is not underlain by igneous rocks, and probably did not originate as the result of submarine igneous activity. It would seem that the Bahamas are continental in character. If this is true, it is probable that the Great Bahama Bank is underlain by material somewhat lighter in density than 2.67, the value used in the isostatic reductions. It is perfectly possible for a small area to show average anomalies equal to those for the Bahamas, and yet be in isostatic balance."

After taking into consideration (*a*) the great depth of the ocean to the east and west of the Great Bahama Bank, (*b*) the fact that material lighter than normal lies just below the station, and (*c*) that the average negative mass which could cause this average negative anomaly is comparatively small, Doctor Bowie comes to the conclusion that:

"The isostatic gravity anomalies at the Bahama stations would have been very much larger, but, of course, still negative, if the deficiency of mass in the ocean waters surrounding the Bahama Bank had not been isostatically compensated. There seems to be good evidence that the Bahama Bank and the surrounding area are in isostatic equilibrium to a marked degree, and that the

Principal Facts at Gravity Stations, Bahama Islands (1930).

Station.	Latitude, ϕ Longitude, λ.		Elevation.	Theoretical gravity, Bowie formula. γ_o	Correction for		Computed gravity. g_c	Observed gravity. g	Isostatio anomaly. $g-g_c$
					Elevation.	Topography and compensation.			
	0	1	Meters	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²
North Bimini	25	43.51	2	979.010	−0.001	+0.041	979.050	979.015	−0.035
	79	18.37							
Billy Island	24	38.95	1.5	978.936	0.000	+0.038	978.974	978.958	−0.016
	78	30.65							
Great Stirrup Cay	25	49.73	14	979.018	−0.004	+0.067	979.081	979.056	−0.025
	77	53.44							
Nicolls Town	25	08.25	5	978.969	−0.002	+0.054	979.021	979.000	−0.021
	78	00.32							
Mangrove Cay	24	16.00	1.5	978.910	0.000	+0.048	978.958	978.941	−0.017
	77	40.54							
Nassau	25	05.04	4	978.966	−0.001	+0.073	979.038	979.025	−0.013
	77	21.00							
Miami (Fla.)	25	42.82	7	979.009	−0.002	+0.032	979.039	979.034	−0.005
	80	15.12							

anomalies at several stations are probably due to abnormally light material close to the stations. It is interesting to note that at two of the Meinesz gravity-at-sea stations in Crooked Island Passage the anomalies are —.033 and —.001 dynes. A Meinesz station about 200 miles east of Great Abaco Island has an anomaly of +.014. That station is well out in the ocean and therefore may be assumed to have an anomaly that is characteristic of ocean stations which are not close to irregular ocean bottoms."

According to Doctor Bowie, Doctor Meinesz has found that the many submarine stations which he has established by the use of a Dutch submarine in the waters surrounding the East Indies show a number of rather large anomalies; but they seem to be rather local, and the region as a whole is undoubtably in isostatic equilibrium. If this is true, it throws new light upon the structure of the East Indian islands.

OCEANOLOGY

The object of the oceanological part of the expedition was to study the character of the waters covering the Great Bahama Bank, as well as the bottom deposits, and to determine, if possible, the source of the finegrained calcium carbonate mud, provisionally termed "drewite." The region in which most of this mud occurs is off the west coast of Andros Island, bounded by the dotted line on figure 1. In order to compare the conditions alongshore and offshore, stations were established 5 miles apart along the lines shown on figure 6. At each of these stations, the following studies and collections were made: (1) Temperature, salinity, and acidity; (2) plankton, both day and night tows; (3) samples of the bottom deposits; (4) direct examination of the bottom conditions, using a diving helmet; and (5) underwater photographs. The average depth of the area surveyed is between 2 and 3 fathoms. During April, the average temperature of the air was 81° Fahrenheit in the afternoon and 75° Fahrenheit in the early morning. The water temperatures showed a diurnal variation between 78° Fahrenheit and 75° Fahrenheit. It is interesting to compare the water temperatures in April with those in August, when the offshore temperatures averaged 86° Fahrenheit and the inshore temperatures 92° Fahrenheit (depths of 1 to 3 feet). The acidity was remarkably uniform, all stations showing a *Ph* of 8.2.

According to Dr. Charles Fish the significant biological characteristic of the waters over the region investigated is the comparative scantiness of the plankton, and especially of the foraminifera. Doctor Fish reports:

"Of the two available sources of support for neritic life in this area—land outwash and the Gulf Stream—the former, consisting of low barrier wasteland,

can obviously contribute comparatively little to the fertility of the waters. The Gulf Stream offers a much more favorable source of supply. The collections extended well into the Santaren Channel which contained the rich pelagic community characterizing the Gulf Stream along the entire course. However, the plankton, except near the margin of the channel, was found to be quite neritic in character, and the examinations made so far have revealed no indication of Gulf Stream influence over the banks. For about two-thirds of the distance from the shore to the slope, the scanty plankton community was very uniform in content. In the remaining distance it became more variable, and although the catch at each station was made up of neritic species, different forms, particularly small medusae, dominated at successive stations."

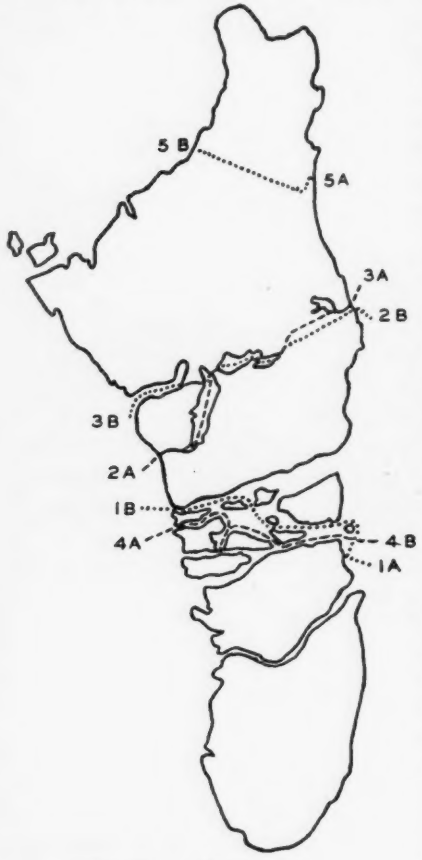
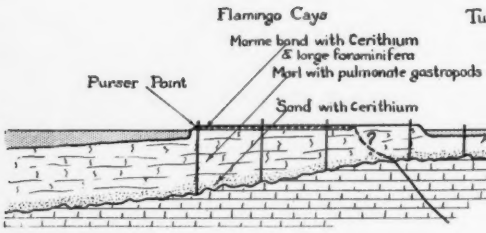
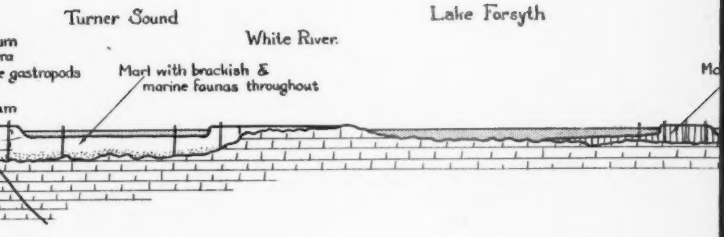


FIGURE 3.—*Andros Island*

Scale 1 inch = 20 miles. The dotted lines show the routes traversed by Mr. Black. For generalized cross-section of Andros Island see figure 4. *1A*, Mangrove Cay; *1B*, Little Loggerhead Creek; *2A*, Purser Point; *3A*, Blue Mountain Creek; *3B*, Goose River; *4A*, Spanish Wells; *4B*, Mangrove Cay; *5A*, Stafford Creek; *5B*, unnamed point on northwest coast.

Information regarding the plankton from a number of the most significant stations is shown in the tables on pages 770-772. It will be noticed that except in a few samples taken near the west coast of Andros Island, there are practically no foraminifera. In these samples the tests occurred together with particles of lime, indicating that they had recently been stirred up from the bottom. Further, the species are identical with the fossil species which form a thin band beneath the calcium carbonate mud formation off the west coast of Andros Island. See figure 4 and figure 5. But


Flamingo Caye
Tu
Marine band with Cerithium
& large foraminifera
Marl with pulmonate gastropods
Purser Point
Sand with Cerithium
?



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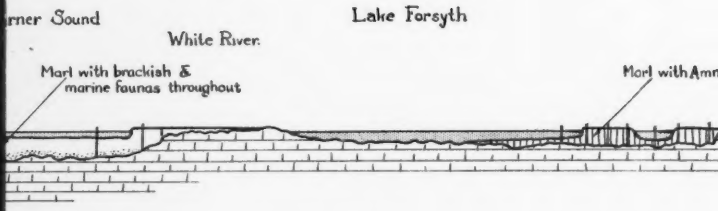

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shore features are not well developed at th
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sediments containing Cerion, etcetera. Dot
miles; vertical, 1 inch = 40 feet.

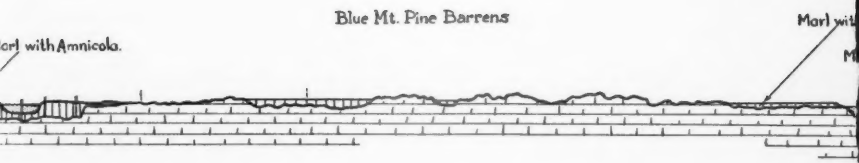
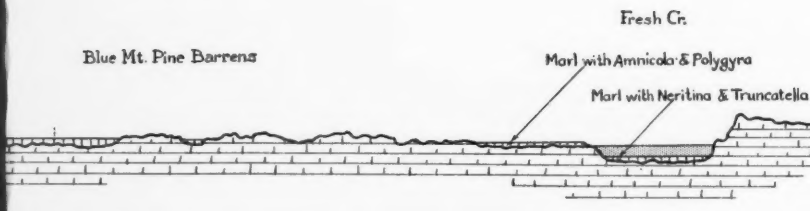


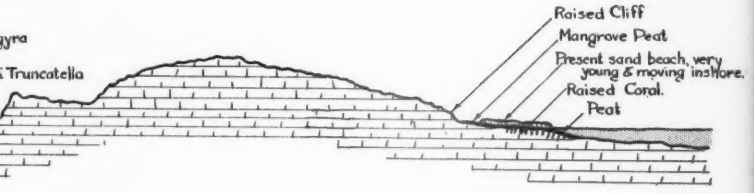
FIGURE 4.—*Cross-section of Andros Island*

ade by Mr. Maurice Black, from Purser Point (*2A*, figure 3) through the inland lakes shown on figure 3.
oped at the entrance to Fresh Creek (*3A*) so the features of the east coast have been projected from
h question mark, near west coast, represents possible unconformity between Turner Sound sediments and
tera. Dotted vertical lines represent location of bore-holes. Approximate scale: horizontal, 1 inch =



ss-section of Andros Island

m Purser Point (*2A*, figure 3) through the inland lakes shown on figure 3. The Creek (*3A*) so the features of the east coast have been projected from Man- ast, represents possible unconformity between Turner Sound sediments and the present location of bore-holes. Approximate scale: horizontal, 1 inch = 1½


gyra
Truncatella
Raised Cliff
Mangrove Peat
Present sand beach, very young & moving inshore.
Raised Coral.
Peat

one specimen of living pelagic foraminifera was found, *Globigerina bulloides* d'Orbigny. Thus pelagic foraminifera are very scarce and could not have any noticeable influence on the bottom deposits. It will be noticed that algae are absent in the plankton except in the Gulf Stream and near the west end of the South Bight. Of the remaining important constituents of the plankton (see tables, pages 770-772) none of them are characteristic of a limy area. For the most part the genera, and in many cases, the species (of the dominant group, the crustacea) are the same as those which occur in all latitudes from the Arctic to the Antarctic;

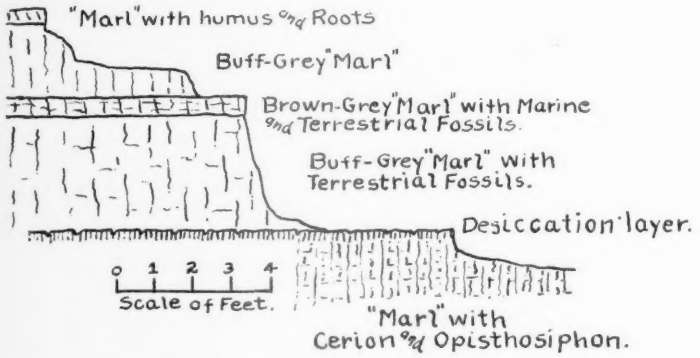

"Marl" with humus and Roots
Buff-Grey "Marl"
Brown-Grey "Marl" with Marine and Terrestrial Fossils.
Buff-Grey "Marl" with Terrestrial Fossils.
Desiccation layer.
0 1 2 3 4
Scale of Feet.
"Marl" with Cerion and Opisthosiphon.

FIGURE 5.—*Cross-section of "cliff" on west coast of Andros Island at Purser Point (2A, figure 3).* Compiled from information from Mr. Maurice Black.

among them, the common copepod of this area, *Acartia tonsa*, constitutes the most common species of the summer plankton at Woods Hole, Massachusetts.

"As most of the collections were made under very favorable weather conditions, it is not possible to state definitely to what extent continued westerly winds may transport forms from the channel onto the shoals. However, considering how sharply the pelagic fauna of the Gulf Stream is normally restricted along its landward margin, it is reasonable to assume that any influx onto the shallow banks off Andros would be sporadic and probably exert little, if any, permanent influence on the local fauna."

Per Cent of $CaCO_3$ in Marine Invertebrates[3]

	High	Low	Average	Numbers from which averages were obtained
Foraminifera[4]	90.11	77.02	86.41	7
Calcareous sponges	84.96	71.14	80.66	4
Madreporarian corals	99.95	97.57	95.88	30
Alcyonarian corals	98.93	72.99	83.66	22
Hydroids[5]	99.63	96.77	98.30	6
Annelid tubes[5]	99.55	89.66	96.07	3
Crinoids	91.55	83.13	87.64	24
Sea urchins	93.13	77.81	87.13	12
Starfishes	91.06	71.28	85.62	29
Ophiurans	92.70	79.37	87.04	17
Bryozoa	96.90	86.89	87.85	13
Calcareous brachiopods	98.61	88.59	96.09	5
Phosphatic brachiopods	8.35	1.18	4.59	3
Pelecypods	99.87	98.60	99.41	11
Scaphopods and amphineurans	99.13	98.37	98.75	2
Gastropods	99.95	96.60	98.73	20
Cephalopods	99.50	93.76	96.21	7
Barnacles	99.07	95.53	97.26	7
Crustaceans[4,5]	82.64	28.65	70.36	13
"Lobster" shells[4]	78.98	55.46	66.57	6
Algae[5]	99.21	73.63	83.19	27
Algae[4]	98.73	79.81	88.90	8

The small proportion of calcareous constituents in the plankton of the waters over the Great Bahama Bank,[6] as well as the meagerness of the plankton as a whole, are significant factors in a consideration of the possible source of the carbonate muds, and also throw some light upon the conditions which may have existed in certain of the "chalk" seas.

Marine Ecology and Character of Marine Sediments

The bottom samples from each station were examined as to both their organic and their inorganic content. It is interesting to note that in spite of the extremely shallow water over the Great Bahama Banks, most of the plankton spent the daylight hours on the bottom, the maximum number of species and of individuals appearing in the night tows. Ac-

[3] Clark and Wheeler: The inorganic constituents of marine invertebrates. U. S. Geol. Survey, Prof. Paper 124, 1922.

[4] Types found in the plankton.

[5] Types found in the benthos.

[6] See table, p. 768.

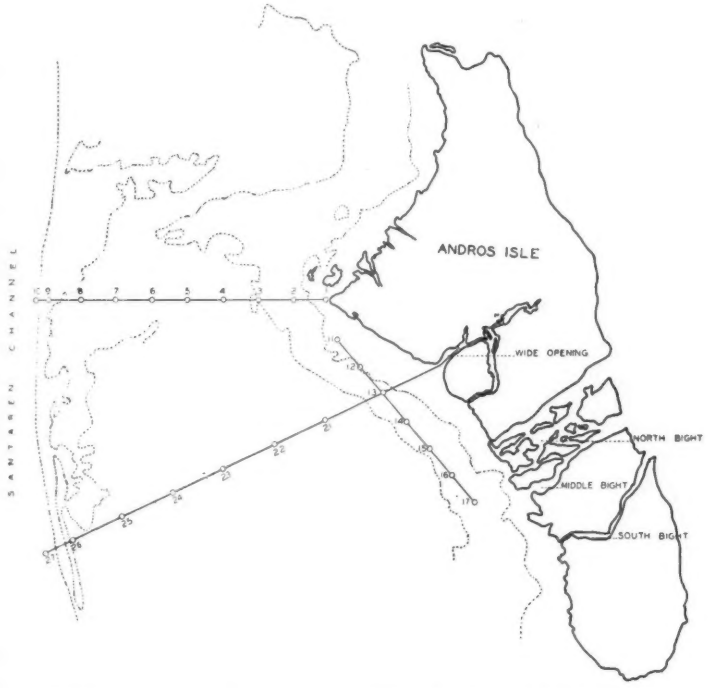


FIGURE 6.—*Location of the marine stations on the Great Bahama Banks* Made during the International Expedition in March and April, 1930. Scale: 1 inch = 25 miles.

cording to the observations made on the benthonic faunas by Dr. Roy Miner and Dr. Ulric Dahlgren, both the invertebrate fauna and the sparse plankton community upon which it feeds are necessarily a resultant rather than a causal factor in the formation of the calcium carbonate muds. The writer agrees with them that the benthonic life on the Great Bahama Banks is in inverse proportion to the presence of the calcium carbonate mud.

According to Dr. Dahlgren,

"The first and lasting impression of the entire region was that of an area in which but few kinds and small numbers of animals and plants could live. The shores and banks on the west coast of Andros Island are composed of lime mud containing numerous fossil shells (plate 20, figure 2). The unconsolidated sediment of the cliffs is prograded to and under the water in a sloping beach to

Analysis of Plankton Collected in August, 1928, and April, 1930, by Dr. Charles Fish and the Writer

Station	Locality	Haul depth	Quantitative contents Per cent	Qualitative content	Remarks
2A	Gulf Stream between Miami and Bimini	Surface No. 20 net.	Crustacea 20 Algae 78 Tunicata 2	Copepods, mostly *Trichodesmium, Appendicularia*	Copepod *C. finmarchicus*, a northern species
13	Outer section Bahama Bank	Surface No. 0 net.	Crustacea 95 Fish eggs 3 Larval fish 5 Pelecepoda 3 Foraminifera 2 Vermes 1	Copepods, ostracods, cumacea, amphipods, schizopods Benthonic species *Sagitta*	Bulk of the plankton derived from the Gulf Stream
17	Off Middle Bight	Surface No. 20 net.	Crustacea 80 Vermes 10 *Foraminifera* 5 Pelecepod larvae 5	Copepods (*Oithona* and *Acartia*) Bottom species	 Particles of lime abundant
21	Inner section of bank on line	Surface No. 0 net.	Crustacea 50 Coelenterata 40 Fish eggs 8 Fish larvae 2 *Foraminifera* trace	Copepods, ostracods, cumacea, decapods, amphipods Medusae 1 specimen (bottom species)	 Few particles of lime
23	Middle of bank	Surface No. 20 net.	Crustacea 60	Mostly young copepod stages of *Oithona*, some Mysid, and Macruran larvae	

			Vermes 10 Fish eggs 8 Larval fish 2 Mollusk larvae 20	Pelecepods and gastropods	
24	Outer section bank	Surface No. 0 net.	Crustacea 70 Vermes 2 Fish eggs 8 Coelenterata 20	Copepods, ostracods, squilla, amphipods, schizopods *Sagitta* Medusae	Few particles of lime
25	Outer part of bank near Santaren Chan	Surface No. 20 net.	Crustacea 95 Vermes 3 Tunicata 5 Mollusca 1 Foraminifera 5	Copepods, ostracods, amphipods, larval decapods *Sagitta* *Appendicularia* Pelecepod larvae Bottom species	Net contained some particles of lime
	In Santaren Chan	Surface No. 20 net.	Crustacea 90 Vermes 3 Fish eggs 4 Coelenterata 20 Annelid larvae 5 Tunicata 5	Copepods, larval schizopods *Sagitta* Siphonophore *Appendicularia*	Typical Gulf fauna

1928

Station	Locality	Haul depth	Quantitative contents Per cent	Qualitative content	Remarks
	Between Round Rock and Turtle Rock	Surface No. 20 net.	Crustacea 90	Copepods, adult and young, decapodlarvae, gastropod larvae	
			Mollusca 7		
			Coelenterata 2.5	Siphonophore bracts	
			Annelid larvae 3		
			Foraminifera 2	Bottom species	
			Globigerina 1 spec.	Pelagic Foraminifera	*Globigerina bulloides*
8	1 mile south of Wide Opening	Surface No. 20 net.	Crustacea 95	Mostly copepods, acartia tonsa; some amphibods and crab larvae	
			Annelid larvae 1		
			Fish eggs 3		
			Mollusk larvae .5	Pelecepods	
			Foraminifera .5	Bottom species	
10	2 miles west of eastern entrance of South Bight	Surface No. 20 net.	Filimentous algae 98		
			Fish eggs 1.5		
			Crustacea .5	Neretic copepods	

form apparently the entire bottom of this shoal region (see area inside dotted line, figure 1). When the sea is agitated by a storm, the finer material is stirred up and the water becomes milky with the fine sediment. In varying periods of time after such disturbances the fine white material settles and the water becomes clear again. It would appear from observations made with a diving helmet on the bottom, however, that a certain small part of this lime sediment remains suspended most of the time. The shore slopes very gradually, the depth increasing so slowly that several miles from shore the sea is only a few feet deep. Sea currents are not strong enough at any point to stir up the bottom or to form marked bars. The following questions arise: How permanent is the bottom in the different areas of the region? What animals can exist? What part do they take in forming the finegrain carbonate mud?"

According to both Doctor Miner and Doctor Dahlgren, the character and ecology of the life on the bank is as follows: The existence of eelgrass or of its roots and rhizomes gives some indication of bottom permanence. This plant is found on the bottom at nearly all points from low-water mark to the edge of the bank. The fact that the bottom is often disturbed by northeast storms does not prevent this plan from maintaining itself over most of the area. Another organism that indicates a bottom surface varying only within a range of several inches is a burrowing crab whose inch-wide burrows are found in abundance wherever the water is more than 4 feet deep. These burrows are closely spaced on the bottom in clear weather, and after a storm, during which the bottom is disturbed and redeposited in layers up to several inches in depth, the holes are reopened and placed in good condition within a few hours. Near the west shore of Andros Island this disturbance of the bottom is most marked, and the only large animal forms found are those that can live in the shifting muds. Crustaceans such as *Crangon,* an amphipod, and several copepods are found here. A few individuals of a small tubularian hydroid were found, and one small polychaete annelid. All sessile forms of life are absent, as well as the usual species that inhabit more or less permanent burrows.

Farther from shore, in only slightly deeper water, a few other forms appear, chitinous sponges, hydroids, crustaceans, and calcareous algae becoming more prominent. Here a much greater degree of bottom permanence exists, although disturbance of the fine-grained calcareous sediment occurs rather frequently, caused by wave action and "bottom stir-up." The sponge colonies and associated fauna occur in places where the hard rock bottom appears near the upper surface of the calcareous mud. These sponge colonies tend to change their position from year to year, and especially after long and severe storms. Few live mollusks were found, and these only in the deeper areas or holes. The bulk of the gastropod shells in the marine sediments are either terrestrial, fresh-water, or brackish

types,[7] and have either been blown into the sea from Andros Island or derived by the reworking of the fossiliferous band of unconsolidated calcium carbonate mud along the west coast of the island. While the larger crustaceans and the few mollusks do undoubtedly contribute to the calcareous deposits, the amount contributed now and in the past must be so small compared with the total amount of the mud that we can not consider calcareous tests of either plankton or benthonic types as making a substantial clastic contribution to the large area of calcareous muds on the bank.

Upon microscopic examination the bulk of the fine-grain mud is found to be composed of crystalline grains of calcite and aragonite, 0.05 to 0.01 millimeters, and fine needles of aragonite 0.003 to 0.005 millimeters in diameter. Tests of foraminifera and sponge spicules were found to be relatively more abundant at some stations. Calcisphaerulites comparable with those found in the chalk of the Moluccas were present. Vegetable debris was sometimes locally abundant but fragments of gastropods, pelecypods, and crustaceans were relatively rare. Further, most of the gastropod débris was derived from land species, or from fresh or brackish-water species. During the three expeditions to the Bahamas the writer has found no evidence of oolites being formed in the deposits on the bank, although certain "flocculent" deposits which appear when the bottom off the west coast of Andros is stirred up are still being investigated. The only lithified oolites that occur in the unconsolidated sediments are found on the east side of the cays bordering the west side of the Great Bahama Bank. These oolites have clearly been derived from the cay rock, which is almost entirely oolitic in composition.[8]

Microbiology

It has been thought for some time that microorganisms probably play a fundamental rôle in the origin of coal and petroleum. It has also become increasingly evident that there is an important relation between microbiology and the origin and alteration of fine-grained sediments (muds), certain types of which may very well be the source beds of petroleum. Although some very valuable work has already been done on the bacteriology of lakes and swamps, the bacteriology of sea water and especially of marine muds, estuarine and otherwise, does not seem to have been given the attention that it deserves.

The writer's particular interest in microbiology has been in its relation

[7] Mr. Black reports large quantities of *Octacocina, Olivella, Caecum,* and small pelecypods from the mud taken at several marine stations.

[8] A detailed description of the sediments will be published later by Mr. Black.

to the origin of the calcareous muds of the Bahamas. Ever since Drew published his account of the rôle of *Bacterium calcis* the writer has leaned strongly towards the supposition that marine bacteria might prove to be an important agent in the precipitation of calcium carbonate mud and hence give us the most logical explanation of the origin of the fine-grained unfossiliferous limestones which become increasingly important as we descend the geological column. During his first expedition to the Bahamas, however, the writer strongly suspected that if bacteria were effective in the precipitation of calcium carbonate it was probably the bacteria in the muds and not the bacteria in the sea water, which would ultimately prove to be the principal agents. This supposition was largely brought about by the intimation that both aerobic and anaerobic micro-organisms were present in the marine carbonate muds, and that these two different types of organisms were responsible for the change in color from white to grey of the calcareous muds from the surface downward.

The microbiological work of the expedition consisted of an examination of the marine sediments on the Great Bahama Bank; the sediments along the shore and on the western edge of Andros Island; material collected from bores made some distance inland from the west coast; and a few analyses of the brackish water and lagoon sediments. (Plate 21, figure 3.) Portions of the marine sediments were sent to Dr. N. A. Cobb, who reports more than 60 genera and 130 species of nematodes. These nematodes indicate a peculiar biocen with instances of commensalism with microphytes, among them Beggiatoa. There are at least three species that appear so intimately connected with micro-organisms, as carriers, that it is difficult to avoid the conclusion that the two are normal commensals. It is interesting to note that the nematodes are practically anaerobic and it is possible that these organisms, especially if they may be proved to be commensal or symbiotic with certain algae, may either directly or through their metabolism cause the deposition of calcium carbonate.

After careful consultation here and abroad with the help of Dr. Selman Waksman, of the Agricultural Experiment Station, New Brunswick, New Jersey, the writer arranged for Dr. Werner Bavendamm, through the Deutsche Forschungsgemeinschaft, to collaborate on the subject of the possible rôle of micro-organisms in the precipitation of calcium carbonate in tropical seas.[9] Doctor Bavendamm made his collections in the Baha-

[9] Doctor Bavendamm's full report will appear in the "International Revue für die gesamte Hydrobiologie und Hydrographie," under the title of "The possible rôle of micro-organisms in the precipitation of calcium carbonate. For preliminary summary see "The Possible Rôle of Micro-organisms in the Precipitation of Calcium Carbonate in Tropical Seas. Science, May 29, 1931. p. 597.

mas under the writer's direction. Great care was taken both in the collections of the samples, and special refrigeration was provided to keep the samples at a low temperature until they arrived at the laboratory. All of the laboratory work was done under the direction of Doctor Waksman. Samples were collected from the muds under the marine waters of the Bahama Bank, from the muds in the low cliffs of the west coast of Andros Island, and from the fresh and brackish-water swamps at some distance from the coast. Relatively few bacteria were found to occur in the marine white calcium carbonate mud, or in the mud from the cliffs on the west coast of Andros (from 5,000 to 100,000 cells per gram of moist mud). In the mangrove swamps the count was much higher. The surface layers contained over 16,000,000 bacteria per gram, and even at a depth of 4 feet, more than 2,000,000 bacteria were found in one gram of material.

After isolation by special cultural methods, a typical microbiological population was shown to exist. Of this population the large sulphur bacteria, *Oscillatoria,* and certain diatoms and protozoa formed the chief part. Several colorless and red colored thiobacteria were also discovered, and it was possible to assign a new position to the rare *Beggiatoa mirabilis* of the Bahama Islands. As to the organisms which may be responsible for the precipitation of calcium carbonate, Doctor Bavendamm reports as follows:

"Apart from the types which Drew and others have erroneously termed 'calcium bacteria,' going so far as to attach special names to them, there were found in many places numerous ureabacteria which to this day have escaped observation. These bacteria, like the denitrifying forms observed by Drew, are able to precipitate calcium carbonate under certain conditions. Also the strictly anaerobic, sulphate-reducing bacteria, which are probably important in the process of calcium carbonate precipitation, were found to exist everywhere. The presence of very active cellulose and hemicellulose-destroying bacteria attracted special attention. These organisms were notable for their ability to dissolve agar-agar made from brown and red algae, and are so abundant that they are believed to be not only responsible for the decomposition of the abundant organic matter in the mangrove swamps but togeter with other bacteria they might well aid in the precipitation of $CaCo_3$."

As the result of their recent experiments, Doctor Waksman and Doctor Bavendamm do not agree with the former ideas of Doctor Lipman (1929) that the great area of calcium carbonate mud in the Bahamas is the result of strictly physico-chemical processes, but they believe that it is rather the result of microbiological processes. Their conclusions have been reached not only from the inspection of crude and pure cultures of the various organisms in the laboratory, but also from the bacteriological-

hydrobiological viewpoint. It is interesting to note, however, that the most favorable locations for the bacterial precipitation of calcium carbonate are not in the marine muds, but in the mangrove swamps, lakes, and brackish-water areas on Andros Island. It would appear therefore that an appreciable quantity of the fine-grained calcium carbonate muds in the Bahamas, no matter what their present location, might have originated under fresh or brackish-water conditions.[10]

Stratigraphy of Andros Island

The location of Andros Island is shown on figure 1 and on figure 6. The island is approximately 140 miles long by 50 miles wide, at its widest point. The easterly coast of the island is bordered by coral reefs and the deep trough of the tongue of the ocean. On the eastern shore, where there is practically no calcium carbonate mud, extremely abundant and diversified life exists, especially on the coral barrier. Here on the sea bottom is a close concentration of a great variety of species of corals, gorgonians, actinians, sponges, annulates, crustaceans, echinoderms, and bottom fishes. The lagoon and the beaches as well, are floored, or covered, with calcareous sand often oolitic in character. There are numerous large clumps of coral, with many other elements of the barrier reef fauna such as the sand-loving species, echinoderms and mollusks. Calcium carbonate mud (drewite) is entirely absent.

Andros is intersected by three straits known as the North, Middle, and South bights (see figure 1). In these bights the fauna is not so abundant as on the east coast but more so than on the west coast, becoming progressively more like the latter as one travels from east to west and approaches the sponge banks. The west coast of Andros is bordered by 2 to 4-foot cliffs formed of unconsolidated fine-grained calcium carbonate mud, which the waves are now cutting back. (Plates 18–19–20.) This mud (drewite) contains 96 to 98 per cent $CaCo_3$ (dry weight), the remaining matter being magnesium carbonate and insolubles, containing only a trace of impurities other than carbonaceous matter. The cuspate shape of the west coast (figure 1) is probably due to the prevailing winds, which are either northwest or southwest according to the season. The dotted line on figure 1 shows the outer boundary of the principal amount of relatively pure drewite, or fine-grained calcium carbonate mud.

There is on the whole good geological evidence that the bulk of the

[10] A summary account of the agar-agar liquefying micro-organisms has been published under the title "On the decomposition of agar-agar by an aerobic bacterium," by Waksman and Bavendamm. Jour. Bacteriology, vol. 22, no. 2. August, 1931.

drewite within the area shown by the dotted line has been derived by wave-cutting from the parent beds in the island. Further, all the biological evidence so far collected and discussed seems to support this thesis. Ernest Dixon, of the British Geological Survey, whose participation in the expedition, at the writer's request, was made possible through the Percy Sladen Trust of London, was the first to draw attention to the fact that most of the fossils occurring in the drewite deposits of the west coast of Andros are terrestrial, fresh-water, or brackish-water forms. Specimens of some of these shells were sent to Dr. Henry A. Pilsbry, who pronounced them to belong only to fresh-water and pulmonate gastropod species identical with those now living on the surface of Andros Island or in its fresh-water lakes. The "cliff" section on the west coast of Andros at Wide Opening, Northwest Point, Purser Point and Goose River, (plate 18) contains a band with abundant marine fossils, mostly gastropods and foraminifera (figure 4). It is interesting to note that the bulk of the mollusks found in the marine muds under the shallow water of the banks must either have been blown into the sea or have been derived from the fossil shells previously enclosed in the drewite deposits of Andros Island.

Maurice Black made a series of traverses across Andros Island, shown by the dotted lines on figure 3. Mr. Black's part of the expedition was financed by the Rouse Ball Fund of Trinity College and the Percy Sladen Trust of London. This expedition was particularly difficult and arduous, and at times dangerous. However, with newly developed types of boring apparatus and motor canoes, Mr. Black was able to pierce the drewite (marl) cover of the island and to determine that it thinned gradually to the east.

Starting from Mangrove Cay (*1a*, figure 3) and accompanied by Kenneth Clark, Davidson Scholar at Princeton, Mr. Black made a traverse around Gibson Cat, through the Middle Bight, to Little Loggerhead Creek (*1b*). Most of the islands examined in the Middle Bight showed solid limestone outcrops, and true "swash" country was not found until the western end of the traverse was reached. From Little Loggerhead Creek the traverse was carried westward along the coast of Andros. At Purser Point (*2a*) a second traverse of the island was made eastward, sinking bore-holes at regular intervals. These bore-holes disclosed depths of a little over 20 feet along the shores of Wide Opening, and as they proceeded inland through the River Lees and Turner Sound the "marl" gradually decreased till rocky outcrops began to appear at the eastern end of the White River. The traverse was continued along the fresh-water lake at the head of this stream, almost to its head. Here outcrops of solid limestone in the center of the island were shown to contain marine fossils.

The traverse was continued on foot, and a number of limestone ridges and intervening sedge marshes were encountered; following the easterly drainage the traverse ended at Fresh Creek (*2b*). During the latter part of the journey, the area covered by "marl" was much reduced and the limestone outcrops became more extensive. On the third traverse, a continuous series of water observations were made from Blue Mountain Creek (*3a*) to Goose River (*3b*). The salinity in the lakes, inland from the White River, was uniformly low; but Turner Sound showed some variation, the average salinity being a little less than half that of open sea-water. The bore-holes also showed the "marl" to increase in thickness westward. The fourth traverse of the island was made from Spanish Wells (*4a*) to Mangrove Cay (*4b*). The Spanish Wells fossiliferous "marl" rests at sea level unconformably upon older limestone, while at Mangrove Cay the solid oolites rise some 60 feet above sealevel. At Stafford Creek (*5a*), the start of the fifth traverse, the expedition encountered strong tidal currents at the mouth of the creek, where it flows between steep limestone walls. Further inland, it widens out into a lake (not shown on the map). A series of observations showed that the temperature and salinity of the water vary strongly with the direction of the wind; the bottom contains a peculiarly mixed assemblage of molluscan shells. Towards the west coast the lake system of the Stafford Creek drainage dies out in a network of cuts in a mangrove swamp, where the water is but slightly brackish.

On his return to Princeton, Mr. Black worked with Doctor Pilsbry on the faunas collected from the bore-holes. None of the "fossils" are older than Pleistocene, and all are similar to present species living in the West Indies.[11] Doctor Pilsbry found no Pliocene forms even in the deepest parts of the bore-holes (20 to 30 feet) which had penetrated the full thickness of the drewite. An important result of Mr. Black's and Doctor Pilsbry's work is that it supports Mr. Dixon's and the writer's view that the source beds of the mud now being deposited on the Bahama Banks show no positive evidence of having been originally deposited in salt water, most of the included shells being either pulmonates or fresh or brackish-water species.

Structural Geology

It will be noted on figure 1 that the western and northern margins of the Bahama Block are bordered by a number of cays. These cays are formed

[11] Mr. Black writes: "*C. rhynsum* was known only as a fossil until we found it living on High Ridge Cay. It was quite a thrill to walk ashore and find palmettos covered with living fossils."

of so-called "oolites" which were described by Maurice Black at the last meeting of the Geological Society. These oolites are characterized by dune structure; they are largely unfossiliferous, but contain a few fossil cerions that are closely related to *C. pillsburyi*, the living form of the present. According to Black,[12] page 290:

"This wide distribution of closely related living forms on the cays appears to indicate that the *pillsburyi* stock was widely distributed in the Pleistocene when the Andros Bank emerged, and now survives in either identical, or somewhat altered forms."

Mr. Dixon examined a number of the western and northern cays, as well as the east coast of Andros Island. His report is as follows:

"Striking changes have been recorded in the visible rocks which form the northern and eastern borders of the Bahama Block. The formations exposed appear to be the remnants of an outer belt of old oolitic dunes and shell-sands with an inner area of soft 'marl,' in which, according to the work of Doctor Pilsbry and Mr. Black and an examination of some marine forms by Dr. Roy Miner, most of the fossils are indistinguishable from living species. Perhaps the most remarkable feature is the character of the lithification, the ooliths having been consolidated and hardened to a condition similar to that of Paleozoic limestone, which has preserved them during the intense subaerial and marine erosion common on subtropical islands surrounded by oceanic deeps.

"Various changes of sealevel are apparent. A raised strand-line which is present along nearly the entire rim of the Block shows evidence of slight but distinct warping. At Nicholls Town, and as observed by Mr. Black at Mangrove Cay, the height of this strand-line above high-water mark is 5 to 8 feet, unusually 7 feet; between Bullock Harbour in the Berry Islands and Great Stirrup Cay it is usually 2 to 3 feet, and nowhere is it more than 4 feet high; at Bimini it is nowhere more than a foot above high-water mark, but at Gun Cay it is slightly higher. Although the old oolites (well-known as the Bahaman oolites) were already indurated and much eroded when this strand-line was formed, nevertheless its age is considerable. This older strand-line (unconformity) is largely covered with a stalagmite-like deposit or alteration product, which is not being formed under present conditions, and on Great Stirrup Cay this stalagmite underlies 20 feet or more of partly consolidated, rounded shell-sand, probably an old dune. (Plate 21, figure 2.)

"The section at the lighthouse hill on Great Stirrup is one of the most varied in the islands.

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[12] Henry A. Pilsbry and Maurice Black: Cerions of Andros, Bahamas; and Henry A. Pilsbry: List of land and fresh-water mollusks collected on Andros, Bahamas. Proc. Acad. Nat. Sci. Philadelphia, vol. 82, December 13, 1930, pp. 289-302.

"Cliff and shore, north of Great Stirrup Lighthouse

	Feet	Inches
"7. White sand of rounded shells, foraminifera, etcetera, mentioned above (exposed)	20	
"6. Old land surface; red-brown, ferruginous and calcareous 'clay' with rectangular slabs of black limestone, glazed pink oolite and 'stalagmite'; *Cerion*, *Helix*, and a few small, broken marine shells	1	
"5. 'Stalagmite' or altered limestone (mentioned above), white, brown, or red, and very hard		1-2
"4. White, unstratified limestone, full of fossil rootlets, 'stalagmite' layers; *Cerion*, *Helix*, and a few broken marine shells	0-3	
"3. Oolite, gray, intermediate in hardness between numbers, 1 and 7	0-5	
"2. Old land surface; litter of angular fragments of hard oolite		2-3
"1. Bahaman oolite, white, hard, here unfossiliferous and of unknown thickness, descending below low-water mark....		

"In beds 1, 3 and 7, similar false dips southward to westward at 25 to 30 degrees occur, but in number 1 other dips in all directions are frequent. Despite this variation the old oolites (number 1) whether on the west, north, or east of the block, dominantly dip towards the interior.

"The scanty, clayey-looking matrix of number 6 is important as it contains iron, which gives it its color, and an insoluble residue now under investigation. The bed resembles the weathered residue of many limestones, but such residue does not appear to be yielded by the Bahaman oolite.

"It is evident from this section that sand-drift, which is going on actively close by, has occurred here at two different times in the past besides during the long period of the formation of the Bahaman oolite. Probably another instance of survival of former conditions is afforded by the living coral reef on the east side of Andros. On the same side, at Nicholls Town, a raised fringing reef with stag-horn coral in position of growth covers a wide area. It rests on a thin breccia overlying an uneven surface cut in the old oolite, but its thickness is unknown because of later peneplanation during the period of the raised strand-line. At Mangrove Cay to the south Mr. Forsyth, the Commissioner, and Mr. Black have found marine strata with several coral colonies in the lowest exposed part of the old oolite. However, we still know too little of other parts of the block to generalize with certainty, and, again, the marine beds found at Mangrove Cay may be at a lower horizon than any of the oolites seen on the west side of the block.

"At some time after the hardening of the old oolite, the white 'marl,' which was investigated especially by Mr. Black, was deposited on the inner part of the block. Unfortunately we have little means of deciding with which of the events recorded on the eastern rim this important deposit was contemporaneous. Some greenish calcareous 'clay' at the bottom of the 'marl' in a trial pit on Gold Cay (Williams Island) contains a little iron and insoluble residue and probably corresponds to the red 'clay' (number 6) on Great Stirrup. Though the fossils in the 'marl' are largely land or fresh-water forms, those in the

highest part on the west coast of Andros (Gold Cay, etcetera) are chiefly brackish-water or marine forms. The initial position above sealevel, therefore, was depressed, as is clear also from the present position of the 'marl,' which covers a large part of Andros Island.

"The changes described above call for little variation from present sealevel, but other evidence indicates greater movements in the past. The 'ocean holes' on the land, as at Nicholls Town, and in the sea, some of which have been sounded by Mr. Forsyth, point, as Dr. Wayland Vaughan has said, to a former elevation above sealevel equal to their present great depth. Conversely, base-leveled platforms higher than the raised strand-line appear to exist in the Berry Islands and along the oolite ridges of the east side of Andros. Direct evidence of unequal movement along one of these ridges, joining Morgan's Bluff near Nicholls Town, is afforded by a series of fault-planes in the seaward face of the ridge. These planes dip towards the ocean, which here descends in a short distance to depths approaching 1,000 fathoms. The angles of the dip of the fault plane range from 30 to 40 degrees."

To sum up: The visible rocks of the Bahama Block show in various ways evidence of many changes and movements; but, allowing for wastage, seem to have returned, on the whole, to much the same configuration and position as regards sealevel as they had originally.

The emergence and submergence of the block naturally brings to mind the possibility of a connection with the lowering and raising of the sealevel as a result of Pleistocene glaciation. These movements of the block can hardly be accounted for by the lowering and raising of the ocean level, according to the figures already worked out by Daly and others, unless we have here, in the geology exposed, the record of the last advance and retreat (melting) of the ice to the north.

In view of the gravity determinations, important results may therefore be expected from a boring in the rim and another in the interior of the block, both for the purpose of obtaining direct evidence as to the underlying formations, and for procuring further data for interpreting the gravity anomalies. Plans are completed for putting down such boreholes, and also for continuing, early in 1931, the survey of the outer islands of the British West Indies from Bimini to Haiti. Included in the survey will be gravity and magnetometer determinations, and submarine profiles by sonic sounding. Upon the completion of Mr. Black's report on the stratigraphy of Andros Island, and with the added data which we expect to get from the study of the outer islands between Bimini and Haiti, next year, it is hoped that we may be able to throw some further light on this fundamental problem of the stability of the structural features and the origin of the sediments which mantle their surfaces.

Summary of Results

1. According to gravity data, the Bahama Block is not underlain by igneous rocks, and probably did not originate as the result of volcanic action; the Bahama Block is approximately in isostatic equilibrium, and has undergone recent oscillation in relation to sealevel.

2. Structural phenomena on the margins of the block indicate long and persistent fault-zones; the block has risen or is rising on the east and is sinking or has sunk on the west.

3. Evidence of the reworking of the sediments exposed in the 4-foot "cliffs" and shore deposits of the west coast of Andros Island, as well as the character of the oolitic cay rocks on the western and northern margins of the Bahama Block, suggest that there have been recent slight oscillations of sealevel, probably diastrophic in character.

4. The Bahama Block, therefore, appears to be unstable, having undergone several slight vertical movements.

5. The biological evidence as to the origin of the fine-grained calcium carbonate mud which makes up the bulk of the marine sediment on the Bahama Bank indicates that these muds have not been derived from the marine plankton or benthos.

6. The microbiological evidence as to the origin of the mud indicates that it is probably not being appreciably increased by bacterial action on the Bahama Bank. Further, bacterial action is probably much more effective in the solution and precipitation of calcium carbonate in the brackish and fresh-water areas on the island.

7. Although local crystallization and lithification of the unconsolidated sediments is taking place, or has recently taken place above sealevel, the carbonate mud as a whole is particularly resistant to lithification, and is reworked over and over again.

8. The present source of the bulk of the marine deposits of the carbonate mud on the Bahama Bank appears to be the mud exposed on the west coast of Andros Island.

9. The carbonate mud that covers a large part of Andros Island, thinning from west to east, contains a large number of various pulmonate and fresh-water shells, besides a number of brackish-water shells.

10. There is at present no direct evidence that either the mud under the sea-water on the Bahama Bank, or that on the island, is of marine origin.

11. The facts so far deduced may have some bearing on the origin of certain Paleozoic limestones known to have been deposited in oscillating geosynclines and cuvettes where relatively large areas of bedded and

shelly deposits have from time to time been lifted slightly above sealevel.

12. Such widespread but local oscillations of calcareous banks suggest the optimum chemical, biochemical, and physical conditions for the solution of shelly calcareous material and its redeposition in the form of carbonate mud, which, because it is relatively insoluble in normal marine waters, may, as in the case of other types of muds, be transported and deposited at some distance from its place of origin.

FIGURE 1.—*North Coast of Billy Island at low Tide*

Difference between h. w. m. and l. w. m. 2 to 3 feet. The 3-foot "cliffs" formed of plastic drewite are being cut back from 1 to 3 feet per year. The black material on the foreshore is largely decaying "sea grass."

FIGURE 2.—*Near View of the "Cliffs" of Drewite which form the entire west Coast of Andros Island*

The cutting back of the "cliffs" is aided by dessication frectures and burrowing crabs. Note the bouldery-like masses (phenoplasts) at the foot of the "cliffs."

NORTH COAST AND CLIFFS OF ANDROS AND BELLY ISLANDS

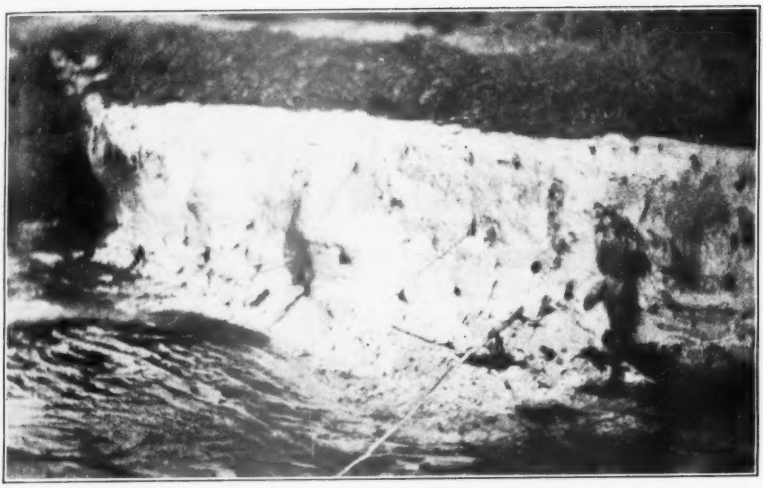

FIGURE 1.—*Near View of the "Cliff"*

Note the holes made by crabs. The drewite is slightly laminated near the base of the cliff. Above the laminated zone the bed is an intraformational conglomerate.

FIGURE 2.—*Soft Fragments of Drewite derived from the Cliff*

The bed which forms the cliff is an intraformational conglomerate, still plastic. The compound intraformational conglomerate now being formed is identical with those found in some of the Paleozoic limestones.

CLIFFS AND FRAGMENTS OF DREWITE

FIGURE 1.—*Desiccation Fractures as shown over a large Portion of Andros Island*

At the locality illustrated the desiccation fractures are of the "limited mud-crack" type owing to the underlying bed being composed of shell-sand. This shell-sand will probably be cemented into coquina in a comparatively short space of time due to the porosity of the sands and the circulation of rain water with calcium carbonate dissolved from the mud-cracked layer.

FIGURE 2.—*Plastic Character of the Drewite which has been washed from the "Cliff"*

Many square miles of this blinding white mud are exposed at low tide off the west coast of Andros Island. The drewite is always pure white or cream colored at the surface, but grades downward (from 1 to 3 inches) into grey or black mud, relatively high in carbonaceous matter.

DESICCATION FRACTURES AND PLASTIC CHARACTER OF DREWITE

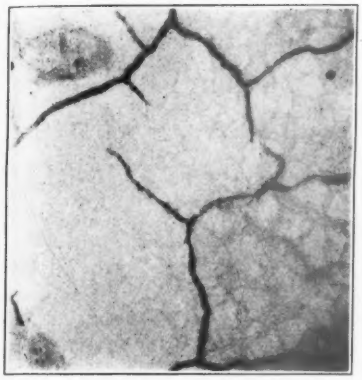

FIGURE 1.—*Surface of mud-cracked Zone of intraformational Conglomerate*

FIGURE 2.—*Sea-cut Platform on west Coast of North Bimini*

FIGURE 3.—*Doctor Bavendamm collecting microbiological Samples near Wide Opening, Andros Island*

Note the "milky" water.

FIGURE 4.—*Gravity Station and Type of Shelter used on the Bahaman Islands*

VIEWS OF BIMINI AND ANDROS ISLANDS

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GEOLOGY OF THE GASPÉ PENINSULA[1]

BY W. A. PARKS

(Presented before the Society December 31, 1930)

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GENERAL STATEMENT

The Gaspé Peninsula may be regarded as the area between the Saint Lawrence River and Chaleur Bay, extending eastward from the Matapedia River to Cape Gaspé. The width, north and south, is roughly 75 miles and the length, east and west, 150 miles.

The strata represented extend from the Cambrian to the Carboniferous; for the most part, they are excessively folded and much affected by

[1] Manuscript received by the Secretary of the Society January 7, 1931.

igneous activity. The peninsula is a structural arc with the convexity northward. At the east end the general strike is a little south of east and at the west end a little south of west. The land rises abruptly from sealevel and has an average altitude of about 2,000 feet. The Shickshock Mountains, with a maximum elevation of 4,350 feet in Tabletop Mountain, form an elevated belt near the north shore; a similar belt of less maximum altitude borders the south shore. The central part of the peninsula is less elevated. The whole area is rough and deeply dissected. In the east are four main rivers (Dartmouth, York, Saint John, Malbaie) in lengthwise valleys, with numerous affluents flowing through crosswise valleys; in the west are several streams in deeply cut crosswise valleys (Bonaventure, Port Daniel, Little and Great Cascapedia, and Matapedia on the south, and Matane, Sainte Ann, Cap Chat, and others on the north).

The summits of the Shickshock are remarkably flat and, according to Alcock, represent the remnants of an ancient peneplain probably of early Tertiary age. Below this higher plateau, and probably extending over the rest of the peninsula, is a second dissected plateau about 1,500 feet lower, representing a peneplain of later age. The raising of this later plateau to an elevation of about 2,000 feet inaugurated the present cycle of erosion, the immature nature of which indicates its recent age. The valleys are sharply V-shaped and the interfluves are flat, but they vary in character with the nature of the rock. The main rivers are navigable with difficulty by canoes, but the smaller streams are impassable. The whole area, except the higher plateau, is densely wooded, and settlement has scarcely invaded the interior; in consequence, the only roads are lumber trails, and many of them are in indifferent condition. The rough and inaccessible character of the country restricted the earlier investigations to the coast and to the valleys of the main streams. More recent work in the interior has been carried on under conditions imposing severe physical exertion. The task of the geologist is rendered still more difficult by the general absence of rock outcrops except in stream valleys and on the higher mountains. The whole surface of the lower plateau is deeply covered by soil and rock fragments and many of the stream valleys are partially filled by talus.

The lack of outcrops and the depth of the soil are due in large part to the absence of continental glaciation. Coleman believes that the Labrador ice-sheet impinged on the north shore, but did not pass over the higher lands. He holds the opinion, however, that a tongue extended southeastward across the lower western part of the peninsula (Matapedia Valley.)

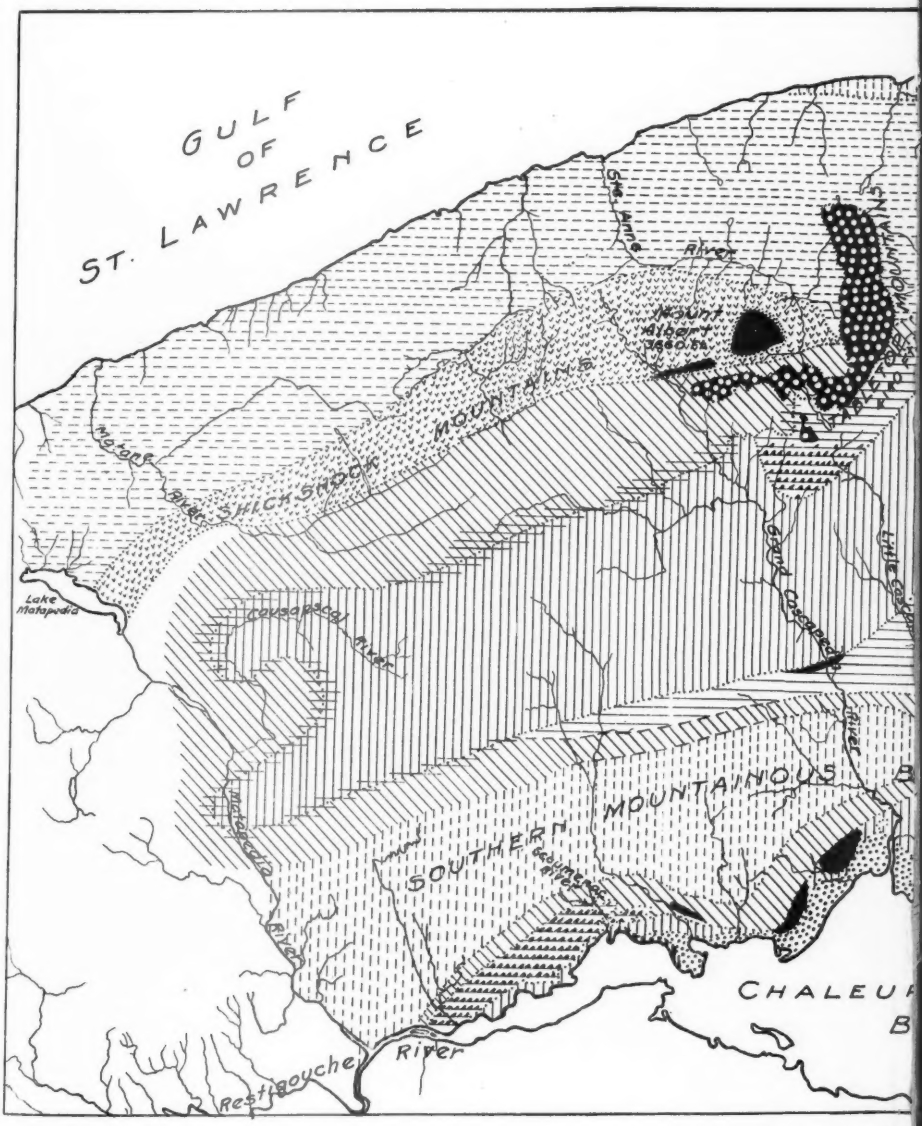
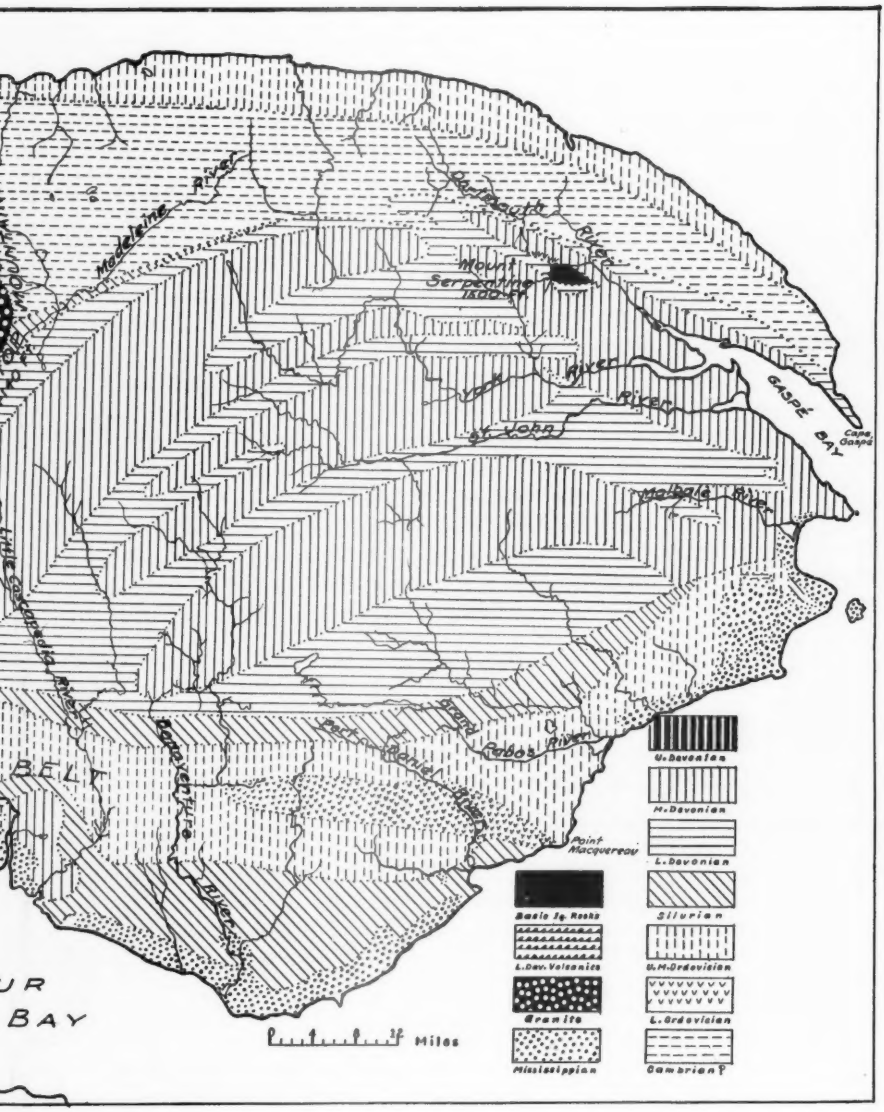


FIGURE 1.—*Map of the*
The geological boundaries are in part conject

FIGURE 1.—*Map of the Gaspé*
The geological boundaries are in part conjectural r



the Gaspé Peninsula
njectural rather than definitely ascertained.

Valley glaciers, on the other hand, were present generally. Striæ in the direction of the valleys, as well as thin accumulations of boulder clay, are common.

Recently, attention has again been directed to the region. The classic monograph of Dr. J. M. Clarke: "Early Devonic History of New York and Eastern North America," has established a basis for Devonian correlation. Professor Schuchert and Miss Dart have done a similar work for the Port Daniel Silurian. The Geological Survey of Canada (Dr. F. J. Alcock) has examined in detail the Mount Albert, Mount Serpentine, and other areas. The newly organized geological section of the Quebec Bureau of Mines has reexamined the Gaspé oil field (W. A. Parks) and the valley of the Cascapedia River (I. W. Jones). Furthermore, in recent years the Geological Survey of Canada has examined in detail the south coast and the region at the head of Chaleur Bay (F. J. Alcock, E. M. Kindle, Cecil Kindle, S. A. Northrop, G. Crickmay, J. H. Howard).

The present paper is an attempt to apply to the whole peninsula the results of observations in limited areas. Many of the conclusions are to be regarded as probable and not as established by direct observation. The accompanying map is to be interpreted as showing the ascertained facts in limited areas and the probable extension of formations beyond the ascertained limits. Much more work is required before the areal geology of the peninsula can be mapped in detail.

Stratigraphy

Table of strata

The strata of the peninsula are indicated in the following table.

Mississippian	**Bonaventure formation.**
Upper Devonian	**Scaumenac fish beds, et cetera.**
Middle Devonian	**Gaspé sandstone series.**
Lower Devonian (Gaspé limestone series)	**Grande Grève.** **Cap Bon Ami.** **Saint Alban.**
Silurian (Chaleur series)	**Indian Point.** **West Point.** **Bouleaux.** **Gascous.** **La Vieille limestone.** **La Vieille sandstone.** **Clemville.**

Upper (?) Ordovician	Mictaw.
Middle Ordovician	Lorraine, Utica — of north coast.
Lower Ordovician	Macquereau series and rocks of Shickshock Mountains.
Cambrian (?)	Levis. Sillery.

CAMBRIAN (?)

The oldest rocks in the Gaspé Peninsula form a great belt extending from Cape Rosier (north of Cape Gaspé) westward to beyond the limit of the peninsula. Except for a narrow belt of later strata on the shore they occupy the whole area between the Shickshock Mountains and the Gulf of Saint Lawrence. Ells describes the strata on the east coast as "red, green, gray, and black shales, with interstratified bands of hard, gray, calcareous sandstone, buff-weathering dolomitic limestone, conglomerates, grit, and shale, the whole presenting a marked resemblance to the recognized Levis beds of Orleans island." In other places the strata are "characteristic Sillery or Pillar sandstone with reddish and gray shales." The strata dip at high angles to the north or to the south and present evidence of much crumpling, but they are less metamorphosed than the rocks of the Shickshock Mountains which seem to overlie them.

There can be little doubt that the strata in question are comparable with the typical Sillery and overlying Levis formations of Quebec city, now believed to be Canadian rather than Upper Cambrian in age as was formerly held; for reasons that will appear later these rocks are indicated as Cambrian on the accompanying map.

Recently a small area of Cambrian has been discovered by Dr. Cecil Kindle inland from Cap Percé on the southern rim of the Gaspé geosyncline. The conclusion is perhaps justified that Cambrian strata were deposited over practically the whole area of the Gaspé Peninsula.

LOWER ORDOVICIAN (CANADIAN)

The oldest rocks on the southern rim of the Gaspé geosyncline are the Macquereau series, compared by Logan with the Sillery, regarded by Ells as pre-Cambrian, and by Schuchert as Canadian, that is, Sillery-Quebec. The rocks are highly metamorphosed sediments and igneous rocks. Talcose and chloritic schists, micaceous gneissic rocks, quartzites, red and green arkose, secondary mica schist and intercalated diabases

are common types. The strike varies from northeast to northwest, but the dip seems to be persistently northward at high angles. These rocks were folded and extensively eroded before the deposition of the overlying later Ordovician strata.

This formation extends westward from the shore at Cape Macquereau; it crosses the East Branch of the Port Daniel River as a wide belt, but it has not been recognized on the rivers farther west, although Doctor Jones has recorded it a short distance east of the Cascapedia River and about 6 miles from the south shore. The continuity of this outcrop with that on the Port Daniel River is not proved.

The Shickshock Mountains constitute a northern belt of rocks regarded by Ells as pre-Cambrian and by Alcock as early Ordovician. The rocks are highly altered sediments and volcanics intruded by masses of peridotite, serpentenized in places, and surrounded by narrow zones of amphibolite. Alcock describes the rocks on Lake Matapedia as reddish, gray, or greenish arkose consisting of quartz and feldspar with calcareous cement, massive greenstones, and altered tuffs. Both Ells and Alcock record a persistently high southerly dip. The latter author proves conclusively that this series is later than the rocks to the north which have been ascribed to the Canadian but which may possibly be Cambrian. The similarity of these rocks to those of the Macquereau series as exposed on the Port Daniel River is striking. It is a reasonable conclusion that the two series are of the same age—early Ordovician, probably Canadian.

It is apparent, therefore, that a difficulty is presented by the relationship of the Shickshock rocks to those bordering them on the north which are also ascribed to Canadian time. Ells avoided the difficulty by making the Shickshock rocks pre-Cambrian and the strata to the north Sillery-Levis, then regarded as Cambrian. This conclusion seems to be justified by the greater metamorphism of the Shickshock series. On the other hand, the Shickshock rocks have little resemblance to the typical pre-Cambrian of the Canadian Shield, and, as already stated, seem to overlie the northern series. If the Sillery-Levis complex is moved down to the Upper Cambrian the difficulty is in part removed but the greater metamorphism of the Shickshocks is still to be explained. For the present they are considered Upper Canadian, and the highly altered condition is regarded as due to shearing along a zone of compression accompanied by the extrusion of much igneous matter.

The northern and southern exposures seem to represent the upturned limbs of a great primary syncline. Furthermore, it is highly probable that the western ends of the limbs were united, thus establishing a basin

open to the east, and into which successive later seas advanced. There is evidence, also, that a similar basin was formed to the south—a basin in which Chaleur Bay now lies.

MIDDLE AND UPPER ORDOVICIAN

In the Port Daniel area, Ordovician rocks were observed by Ells and later were described in more detail by Schuchert and Dart. Dr. Stuart Northrop examined these strata for the Geological Survey of Canada and described them as "fairly rapid alternations of black, more or less bituminous shale and greenish tufaceous graywackes." The belt reaches a width of 6 miles, the dip is at fairly high angles to the south, the contact with the Macquereau is strongly unconformable, and the age is regarded as probably Upper Ordovician. Ells' map shows the same series north of the Macquereau belt and along the shore westward to the Pabos River. Clarke regards these rocks as "metamorphic Siluric."

The southern mountainous belt on the Cascapedia River shows similar strata, although Doctor Jones is of the opinion that they are Silurian slates and limestones, infolded towards the east with some Devonian. Still farther west, on the Matapedia River, is a belt 20 miles wide of highly folded rocks, mapped by Ells as Silurian. The writer has briefly examined these strata and is strongly of the opinion that they are comparable with the strata at Port Daniel and on the shore east of Cape Macquereau. In consequence, the map herewith shows a broad belt of Ordovician strata extending along the mountainous southern side of the peninsula from Cap Percé to the Matapedia. It is to be understood that this continuity is far from proved.

Theoretically there should be a band of this age south of the Shickshock Mountains but there is no evidence in support of this view. Either the Ordovician sea did not advance so far north, or a fault has let down Silurian and Devonian strata against the early Ordovician rocks of the mountains. There is no doubt that this Upper (?) Ordovician sea overflowed the denuded summit of the southern limb of the primary syncline, whereas there is no evidence that the northern limb was thus covered.

Ordovician strata occur, also, along the north shore from near Cape Gaspé to the mouth of Massouin River in a belt with a maximum width of about 6 miles. Ells described the rocks as gray and black slates with hard, gray limestones and cherty feldspathic slates carrying fossils indicative of Lorraine and Utica time. The strata are greatly folded, and the prevailing dip, although sometimes reversed, is southward at high angles. These rocks apparently underlie the older strata to the south;

it is necessary therefore to assume a fault of considerable displacement as marking the southern border of the belt. Clarke's map ascribes these rocks to the "Lower Siluric" but the reasons for the change are not stated.

SILURIAN

The Gaspé limestone series, regarded by Ells as chiefly Silurian, has been proved by Clarke to be of Lower Devonian age; further, Ells' maps show no differentiation of either the Silurian or Devonian, and in consequence it is very difficult to interpret these maps in terms of the more modern nomenclature.

Schuchert and Dart have clearly defined the Silurian (Chaleur series) in the Port Daniel area and have divided it into seven formations reaching a total thickness of 5,079 feet. The rocks are folded and dip at high angles with no apparent unconformity against the underlying Ordovician strata, but Schuchert describes the contact as a "probable disconformity." Definite Silurian fossils are reported from the forks of the Scaumenac River, from a point on the shore midway between the little Cascapedia River and Black Cape on the Matapedia, and on other rivers flowing into Chaleur Bay. The general conclusion is drawn that a Silurian belt extends along the southern side of the peninsula, south of the Ordovician, from Port Daniel westward to the mouth of the Restigouche where it crosses the river and probably swings back to the east on the south side of the bay. The limits of this belt, as shown on the map, are quite conjectural.

The relation of the Silurian to the Upper Ordovician is that of "probable disconformity" in the Port Daniel district, according to Schuchert. Farther west, the strata of both systems are more folded, and in many places on the Matapedia River they are vertical. Here, however, there is evidence of a considerable hiatus between the systems as indicated by distinct unconformity.

The occurrence of a belt of Silurian north of the Ordovician axis of the south side of the peninsula seems to be indicated although definite proof of its width or its length is lacking. Ells considered the whole region on the Cascapedia between the Devonian of the interior and the Devonian of the coast as Silurian. Jones endorses this view but thinks some Devonian is included. The southern margin of this belt is definitely Silurian and Ells' remarks would lead to the same conclusion for the northern margin. In any event the Silurian of Ells must stand unless there is a real reason for a change. The writer is of the opinion that the axis of the belt must be Ordovician, but there is no reason to think that the northern margin is

of this age, therefore, it must stand as Silurian. The uncertain relations of the two systems and the paucity of fossils make the separation difficult. To the eastward this belt of Silurian does not reach the shore. The extent in this direction as shown on the map is quite provisional. Westward from the Cascapedia, in the lack of more modern investigation, Ells' conclusions must stand. His map shows the Silurian as sweeping around the western end of the interior area of Devonian and extending as a band along its northern side. This northern band is mapped by Alcock in the Mount Albert area as "Lower Devonian and Silurian." Jones considers that part of it is definitely Devonian. It is known on faunal evidence that the Silurian occurs on the Isabelle River and reaches as far east as the Madeleine River. An attempt has been made in constructing the map to show by overlapping lines the doubtful separation of the Silurian and Lower Devonian. Ells states that the Devonian (Gaspé sandstone series) on the Causapscal River shows limestone at the base. This limestone is probably of Lower Devonian age. It seems fairly certain that a Silurian belt lies south of the more altered rocks of the Shickshocks and that this belt is succeeded by or infolded with Lower Devonian limestones along its southern margin.

LOWER DEVONIAN

The Gaspé limestones of Logan, considered Silurian by Logan and Ells and mapped by the latter author with other Silurian rocks, form the typical Lower Devonian as determined by Clarke, who has divided the series into three formations. The rocks, on or in the vicinity of the eastern coast, are chiefly thin-bedded limestones, highly fossiliferous in places. Inland, however, as on the Darmouth, York, and Saint John rivers, fossils are few or absent and the limestones are highly siliceous, passing in places into bands of chert. This condition is probably due to the outpouring of ashes from volcanoes farther east. The relationship with the Silurian is not shown in the section on the east coast. In Cape Gaspé the northern margin of the Lower Devonian is faulted against Cambrian strata; the southern margin of the Lower Devonian area lies on the Upper (?) Ordovician, but as already seen, a Silurian belt intervenes a short distance inland. Elsewhere the relationship seems to be that of erosional disconformity or even of unconformity. It seems reasonably certain that both the Silurian and Lower Devonian seas filled the interior basin of the peninsula, the latter to a somewhat less extent, not reaching west of the Matapedia River. The Lower Devonian outcrops would appear, therefore, over the whole of the basin within a ring of Silurian, were it not for covering by later strata. As a matter of fact, the Lower

Devonian does appear south of the northern Silurian belt and north of the southern Silurian belt in the eastern part of the peninsula at least as far west as the Cascapedia River. West of this river the occurrence of Lower Devonian strata is uncertain but there is some evidence of its presence; in consequence, it is shown by overlapping lines on the map. The actual outcrops in the interior of the basin are determined by subsequent folding and the erosion of the overlying Middle Devonian sandstones along the crowns of the anticlines.

Jones describes the rocks of the Lower Devonian belt south of Mount Albert as "a belt 8 miles in width, with elevations from 1,800 to 2,900 feet above sealevel." The rocks are limestones, slates, sandstones, and quartzites.

The Lower Devonian sea invaded also the Chaleur syncline but actual outcrops in Gaspé are found only in the region near the head of the bay, from the mouth of the Scaumenac River to the mouth of the Matapedia. The sediments are interstratified with and invaded by basic igneous rocks. Ells' map shows a large area of dolerite but there is little doubt of the mixture of these rocks with sediments. The Lower Devonian strata are folded and faulted, in many places are vertical in position, and seem to be as greatly disturbed as the Silurian and Ordovician. Logan and Clarke both state that the relation with the overlying Middle Devonian is one of conformity but I am inclined to question this conclusion at least for the eastern region; Alcock has expressed himself in favor of an unconformity between the two series in the Mount Albert area.

MIDDLE DEVONIAN

The Middle Devonian was a time of shallow and fluctuating seas alternating with longer periods of fresh-water conditions in the Gaspé geosyncline. The rocks in the eastern region are shales, sandstones, and conglomerates reaching, according to Logan, a thickness of 7,036 feet and by him called *Gaspé sandstone series.* The rocks are mostly of terrigenous origin and contain vegetable fragments and resinous matter; intercalated with these layers are thin beds containing marine fossils. Jones records marine fossils as far west as the Cascapedia River and Ells states that "great quantities of fossils which are principally of the horizon of the Oriskany and Hamilton formations" occur on the Causapscal River. This reference to Oriskany fossils is one reason for assuming Lower Devonian in the western end of the basin.

In the eastern part of the basin the sandstones lie invariably on the Lower Devonian limestones; on the Cascapedia they are separated from

the Lower Devonian to the north by a series of basic volcanics and from the Silurian (Lower Devonian ?) to the south by basic intrusions.

Within the Gaspé geosyncline the sandstones, together with the underlying limestones, have been folded into long ridges with the strata in places almost vertical. Four major anticlines were recognized by Logan in the coast section. In general it may be said that the denudation of the crowns of the anticlines has exposed the Lower Devonian limestones. The areal distribution of the limestone belts is usually in accord with the general structure of the peninsula but the boundaries as shown on Ells' maps are often inaccurate owing to the necessity for much conjecture in connecting observations on different rivers across an unexplored interval. The map accompanying this paper is subject to the same fault but it is more accurate in the eastern region and on the Cascapedia. The connection of the Cascapedia sandstone belt to the east as shown is not proved; it may with nearly equal probability join the more southerly sandstone bands to the east or even fail entirely eastward. The continuity of this broad belt westward from the Cascapedia is open to doubt but no detailed information is available. Where seen by the writer on the Matapedia River the rocks ascribed by Ells to this division are highly metamorphosed shales and indurated sandstones standing at high angles. According to Jones the sandstone belt on the Cascapedia represents a single syncline with the axis in the southern half.

The folds in the extreme east of the peninsula seem to be *en echelon* rather than continuously parallel. The sandstones in the synclines do not, as a rule, dip towards the axis but show a strong and persistent inclination to the west, indicating synclines plunging in that direction. Conglomerates, with pebbles largely of volcanic origin, and red shales are more common in the upper beds of the series. The total erosion is enormous; not only has the 7,000 feet of sandstone been removed from the anticlines but hundreds of feet of limestone as well. Inland from the east coast little or no conglomerate is found in the synclines and the thickness of the remaining sandstone and shale seldom, if ever, exceeds 3,000 feet as shown by numerous wells drilled for oil. The sandstones are widely petroliferous. Up to about 30 years ago more than 50 wells had been drilled but without commercial yield although oil in some quantity was obtained. It is not impossible that further efforts might be crowned with success.

Middle Devonian sandstones and conglomerates occur also in the Chaleur geosyncline; they have been recognized east of the mouth of the Cascapedia and for a considerable distance along the shore in the inner

part of Chaleur Bay. The fauna is unique and consists of some types surviving from the Lower Devonian mingled with preponderating species of Hamilton age.

UPPER DEVONIAN

It is considered by some authors that the upper part of the Gaspé sandstone series may be of Upper Devonian age but the true Upper Devonian of Gaspé is of the Old Red Sandstone facies and occurs chiefly as a strip on Chaleur Bay extending for 2 or 3 miles west from the mouth of the Scaumenac River. An interesting fish fauna has been described from these rocks.

MISSISSIPPIAN

The Bonaventure formation ascribed to this system occurs along the east and south shores as a narrow strip, interrupted in places, from near Malbaie on the east to the mouth of the Restigouche. The formation is composed of coarse reddish conglomerates and shales; it is apparently of fresh-water origin and lies with profound unconformity on the older rocks. The strata are almost horizontal, indicating little or no subsequent folding. This formation is evidently the result of fresh-water dammed by an eastern barrier in the Chaleur geosyncline; it is exposed, also, on Heron Island and sparingly on the south side of Chaleur Bay in New Brunswick.

Orogeny and Paleogeography

The arclike folding of Gaspé is generally regarded as a special development of the Appalachian system due to thrust against the resistant rocks of the Canadian Shield.

As the so-called Cambrian of the north and the Canadian strata of the Shickshocks and of the Macquereau series seem to be conformable and to have generally similar attitudes, it would appear that extensive folding occurred in the interval between Canadian and Upper Ordovician time establishing the Shickshocks and the southern mountainous belt as the north and south rims respectively of the Gaspé geosyncline. It seems probable that a second syncline was formed to the south—the Chaleur geosyncline. Middle and Upper Ordovician seas advanced into the gulf north of the Shickshocks as a subsequent fault has let Middle Ordovician rocks down against the Cambrian along the coast. Upper Ordovician seas advanced into the south part of the Gaspé geosyncline, overflowing its southern rim, and extending well to the west.

Orogenic movements of some intensity followed the deposition at the Upper Ordovician strata; these were succeeded by a period of erosion and

by a down-warping of both the Gaspé and Chaleur geosynclines. Silurian seas invaded both these depressions and it is possible that the intervening anticline was again overflowed but this conclusion is more doubtful. The Silurian sea in the Gaspé geosyncline advanced farther north than the Ordovician but probably not so far to the west.

Lower Devonian seas followed the Silurian into both geosynclines after minor disturbances and a short period at erosion.

With Lower Devonian time was inaugurated a period of intense orogenic movements that culminated in post-Middle Devonian time.

Middle Devonian seas invaded both the Gaspé and the Chaleur geosynclines, advancing in the former nearly to the Matapedia and in the latter to the mouth of the Restigouche. Marine waters, however, were replaced by fresh water during most of Middle Devonian time. After the deposition of the Gaspé sandstones the folding inaugurated in Lower Devonian time became intense. All strata from Upper Ordovician to Middle Devonian are so much affected by this period of disturbance that the relationships between them are obscured. Extensive faulting also occurred. A great displacement let down Middle Ordovician rocks against the Cambrian belt along the north shore; another south of the Cambrian let down Lower Devonian and Silurian against the Cambrian or against the Canadian strata of the Shickshocks; several major faults parallel to the general folding cut the Gaspé sandstone series of the eastern part of the peninsula.

In Mississippian time fresh-water conditions prevailed in the Chaleur geosyncline but not in the Gaspé geosyncline. Post-Mississippian disturbances are not indicated except by general raising and lowering of the whole area.

Clarke has postulated a land mass in Paleozoic time to the east of the area under review; there is much evidence in support of this view, for example, the character of the Gaspé sandstones, the greater quantity of conglomerate towards the east, and the landlocked basins of Devonian and Mississippian time.

Epeirogeny

Epeirogenic effects can not always be separated clearly from those commonly called orogenic. In the Gaspé Peninsula, however, there is evidence of movements subsequent to the time of the manifestation of mountain-making forces. In this connection, there is evidence of a series of faults transverse to the general folding. The skyline of Cape Gaspé suggests a series of step faults, and the parallelism of the rivers in the west

and of the affluents of the rivers in the east leads to a similar conclusion. Clarke has definitely determined faults of this kind at Percé.

In the Gaspé oil field it has been noted that the synclines plunge westward suggesting a differential elevation in the east.

Alcock believes that the flat tops of Mount Albert and Tabletop represent a peneplaned surface of early Tertiary age. Uplift occurred and a second cycle of erosion produced a mature surface with remnants of the harder rocks surmounting it. Elevation again took place in late Tertiary time inaugurating the present cycle of erosion. Finally there was a temporary depression due to the weight of the ice during the Glacial period.

VULCANISM

CANADIAN

Igneous activity was intense in Canadian time. The Shickshock Mountains are composed of highly metamorphosed rocks in large part of igneous origin. The chief rock is greenstone showing alteration in a manner so varied that its original character is obscured. Augite is a common mineral, and amygdaloidal structure attests the volcanic origin of the rock. Chlorite schist may be regarded as the second most abundant type.

In the Macquereau series diabases in various stages of alteration are common, and chlorite and other schists, probably of igneous origin, are mingled with metamorphosed sediments.

Later than the rocks described above are the peridotite masses of Mount Albert and Mount Serpentine. All of these rocks show a considerable percentage of olivine, and they present various stages of serpentinization. The Mount Albert mass is surrounded by a zone of amphibolite probably representing the first stages of the intrusion. The age of these igneous rocks is not certain but the available evidence points to late Ordovician or at least pre-Silurian time.

SILURIAN

The close association of Silurian and Lower Devonian strata and the erroneous extent given the former system on the older maps make difficult the interpretation of certain statements as to volcanic phenomena. There is no doubt, however, that volcanic activity played a prominent part in the Chaleur geosyncline in Silurian time. Basaltic flows aggregating 3,500 feet in thickness are known to be associated with Silurian strata in the section at Black Cape on the south shore, and deposits of volcanic ashes are mingled with marine sediments of the same age. It is probable also that vulcanism was equally prominent in the Gaspé geosyncline.

LOWER DEVONIAN

The Lower Devonian sediments of the Mount Albert area are associated with volcanics, and large areas of basic volcanics are interbanded with sediments of this age on the north shore of Chaleur Bay.

The Gaspé limestone, soft and fossiliferous in the extreme east, becomes highly siliceous, even flinty, as one advances westward toward Mount Serpentine. More than 2,000 feet of limestone average at least 25 per cent in silica. This immense quantity of silica could have been derived only from the leaching of ashes discharged from great volcanoes in the heart of the peninsula.

MIDDLE DEVONIAN

A thick series of basic volcanics underlies the Middle Devonian in the section along the Cascapedia River and dykes of similar rocks cut the Gaspé sandstones in many places. Alcock records, also, acid flows of this age in the Mount Albert area.

Granite, syenite, and porphyry, probably of Late Devonian age, form Tabletop, Barnshaped Mountain, and other conspicuous elevations to the eastward of the main range of the Shickshocks. Late Devonian granitic batholiths are a feature of the Maritime Provinces of Canada and the eastern part of the Province of Quebec.

The conclusion seems justified that igneous activity was intermittently manifest throughout the area of the Gaspé Peninsula from early Canadian time to the close of the Devonian.

Economic Geology

ZINC AND LEAD

Veins carrying sulphides of zinc and lead occur in a zone of brecciated Lower Devonian strata near Brandy Brook, a tributary of the Grand Cascapedia River. The district is cut by dykes of syenite and porphyry believed to be cogenetic with the Tabletop granitic batholith. These acidic intrusions are regarded as the source of the sulphides. The Federal Zinc and Lead Company is the chief operator. The production to date is small but prospecting is revealing more veins and the hope is entertained of eventual commercial success.

COPPER

Chalcopyrite occurs in the Mount Serpentine region on the Dartmouth river, but no serious attempt to develop the prospects has yet been made.

ASBESTOS AND CHROMITE

The serpentinized peridotite of Mount Serpentine and Mount Albert shows in places small grains of chromite and stringers of asbestos. Neither mineral has been found in commercial quantity.

PETROLEUM

The Gaspé sandstones of the eastern part of the peninsula have long been known as a source of oil. The proved petroliferous area is the eastern part of the region drained by the York, Saint John, and Malbaie rivers. Prior to 1900 some 50 wells were drilled to depths of about 3,000 feet, through the Gaspé sandstones and often into the underlying limestones. The production was sufficient to justify the erection of a refinery in 1901. Shortly afterward, however, the supply failed and the enterprise was abandoned. Some of the old wells that have not been plugged are still discharging a small quantity of oil. In view of the unfortunate location of many of the wells it can scarcely be said that the possibilities of the field are exhausted.

This area is remarkable also for the large quantity of resinous matter in the sands and for the occurrence of bitumen in cracks and cavities in the limestones.

At Port Daniel both the Macquereau and the Mictaw series carry bituminous matter, but nothing of commercial value has hitherto been discovered.

A full account of the oil and bitumen of Gaspé may be found in Part B of the "Annual Report" of the Quebec Bureau of Mines for 1929.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PENNSYLVANIAN SECTION IN WESTERN ILLINOIS[1]

BY HAROLD R. WANLESS

(Presented before the Paleontological Society, December 30, 1930)

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INTRODUCTION

When A. H. Worthen and his associates first studied the Pennsylvanian rocks of Illinois about 1870, they derived from the strata exposed in the valley of Spoon River in Fulton County a stratigraphic section that was used "for the coordination of the coal strata for the central and western parts of the State."[2] Since then many detailed studies of local areas in this part of Illinois[3] have provided much additional information, but no generally accepted correlation. A systematic review of the Pennsylvanian stratigraphy was therefore begun by the writer, assisted by Mr. Sidney E. Ekblaw, in 1929 and continued in 1930 (figure 1).

Earlier investigators considered that the Pennsylvanian strata in western Illinois were marginal deposits in a sedimentary basin, the boundaries of which were nearly the same as those of the present Eastern Interior Coal Basin; that the higher strata overlapped to the margins of the present basin; and that most of the beds varied so much in such short distances that the details were of no value in correlation. The features that led

[1] Published by permission of the Chief, Illinois State Geological Survey.
Manuscript received by the Secretary of the Society March 2, 1931.

[2] A. H. Worthen: Geology of Fulton County. Geol. Survey of Illinois, vol. 4, 1870, p. 92.

[3] See publications of Illinois State Geol. Survey and U. S. Geol. Survey.

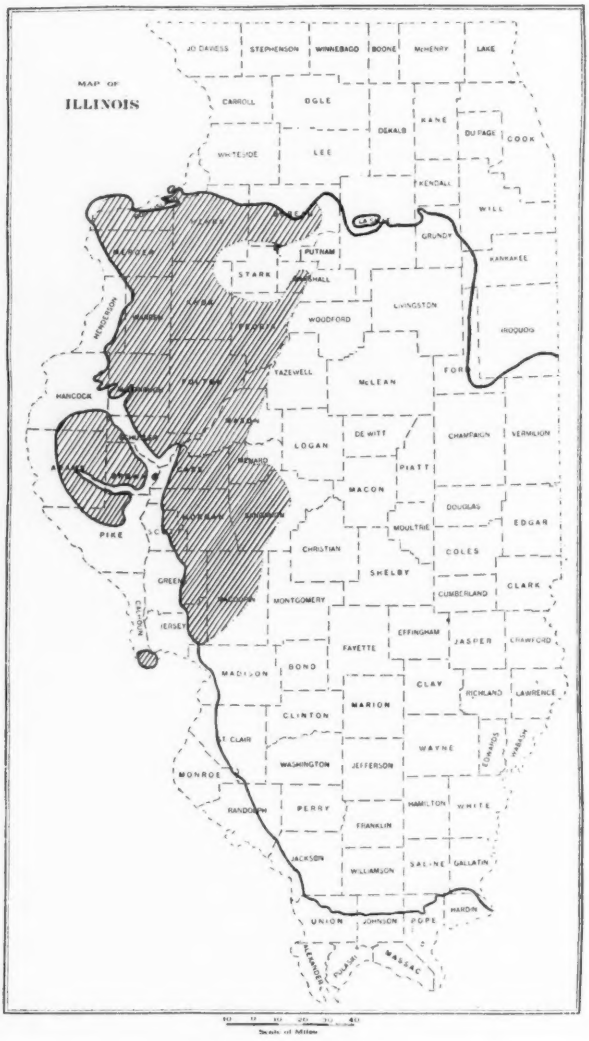


FIGURE 1.—*Map of Illinois*

Showing boundary of area underlain by Pennsylvanian strata, and, by shading, the area discussed in this paper.

them to ignore the persistence and stratigraphic importance of the thinner members were the youthful topography of the region, the irregularity of the preglacial surface, the heavy drift mantle, the regional variation in thickness of all of the Pennsylvanian strata, the local variation of many persistent beds, the truncation of thin shale and limestone beds by channel sandstones, and the attention centered on coals of workable thickness. The current study demonstrates that the persistence of many thin beds indicates uniform conditions of sedimentation over wide areas.

The strata occur in repeated sequences, each of which, beginning at the base, consists typically of (1) sandstone, (2) sandy shale, (3) "freshwater" limestone, (4) coal, (5) carbonaceous shale, (6) limestone and calcareous shale, and (7) clay shale with ironstone concretions. An unconformity commonly separates two sequences. These sequences, representing cycles of sedimentation,[4] are herein termed *cyclical formations* and are used for stratigraphic correlation.

The aggregate thickness of the section of Pennsylvanian strata thus far studied is about 700 feet. The section includes the strata from the base of the Pottsville series to the Shoal Creek limestone, about 300 feet above the base of the McLeansboro series (figure 2), and is divided into 22 cyclical formations; to 18 of these geographic names are herein applied. In 20 of the cyclical formations there are coal beds, in 19 there are marine fossiliferous horizons, and below the basal sandstones of 14 there are erosional unconformities.

The gradual thinning and final disappearance of coals, shales, and sandstones toward the southwest constitutes the principal regional variation in the geologic section (figures 3 to 7); this variation is evidently the effect of a positive area extending eastward from the Ozark highlands, that must have been too near sealevel to have provided much clastic sediment. The presence of limestones in this area proves that it was entirely submerged during some of the greater marine inundations.

Earlier Pottsville Strata

In Rock Island County, Illinois, and in Muscatine and Scott counties, Iowa, the earlier Pottsville strata attain a maximum thickness of about 100 feet and include five coal beds, in which the coal varies in thickness from 3 feet to 1 inch within a fraction of a mile and which at some places are indicated only by bands of pyritic concretions. The coals are commonly overlain by black or dark blue-gray shale and locally by thin

[4] J. M. Weller: Cyclical sedimentation of the Pennsylvanian period and its significance. Jour. Geol., vol. 38, 1930, pp. 97-135.

or irregular dark-colored limestones and pisolitic limestone concretions with cone-in-cone structure. Strata of this character have been found

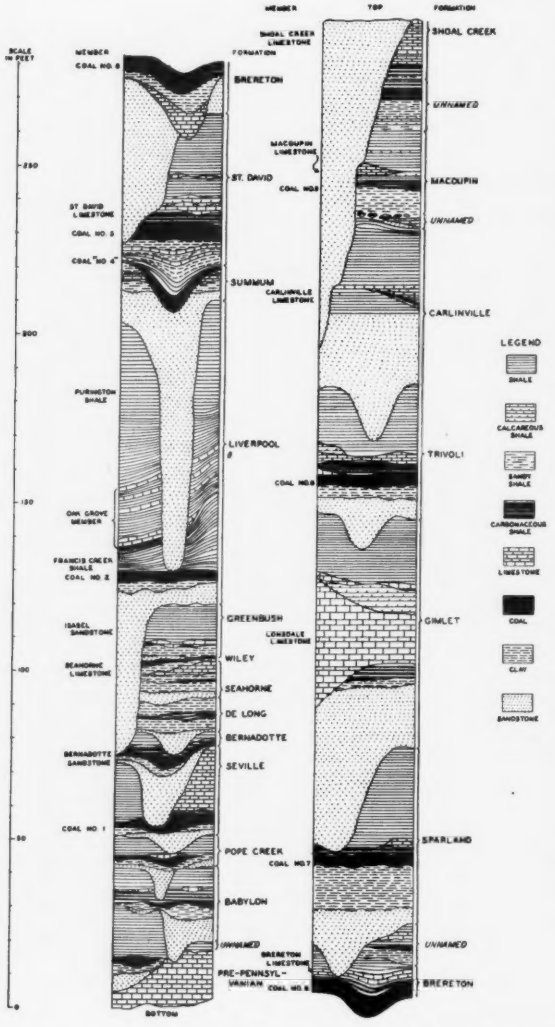


FIGURE 2.—*Generalized stratigraphic Column of Pennsylvanian Strata* Exposed in western Illinois.

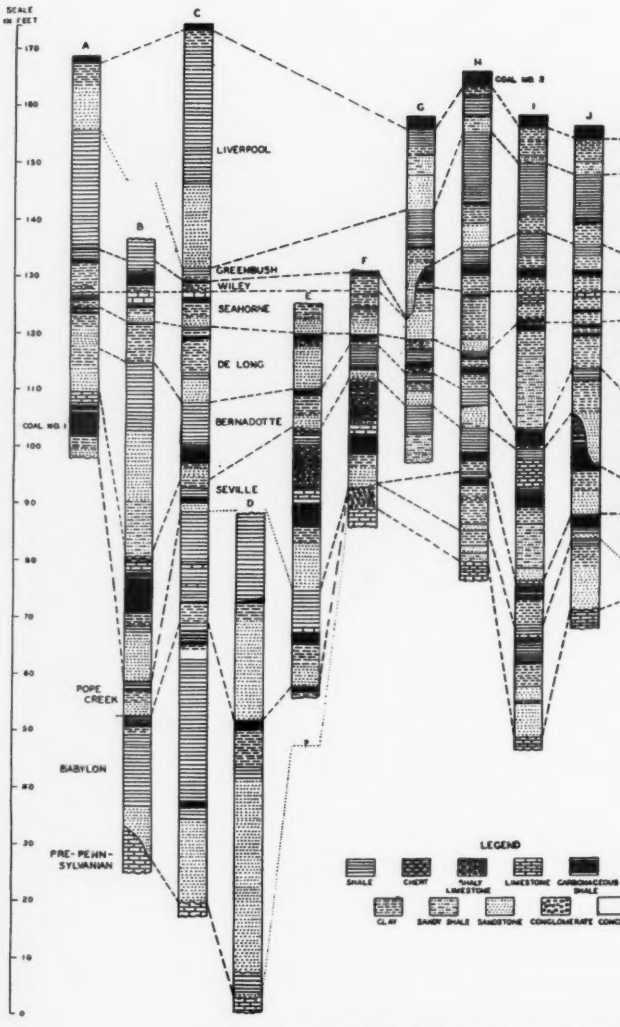
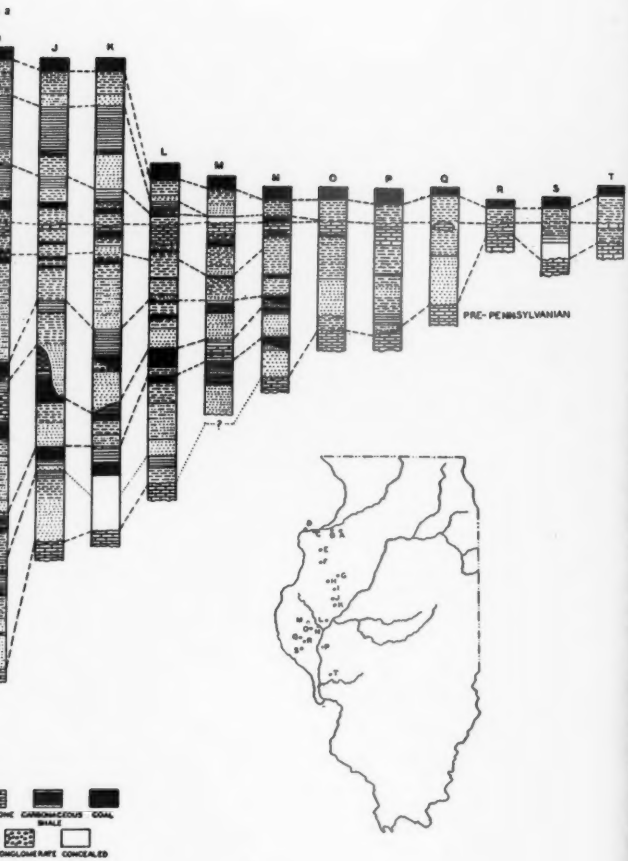


FIGURE 3.—*Diagrammatic Representation of mea*
ville Strata between Coal Number 2 and the
Showing the Liverpool, Greenbush, Wiley, Seahor
Creek, and Babylon cyclical formations a



on of measured stratigraphic Sections of Potts-r 2 and the pre-Pennsylvanian Formations

ey, Seahorne, DeLong, Bernadotte, Seville, Pope mations and the number 1 coal member.

only in the older Pottsville beds. The coals are underlain by siliceous clays and light-colored nonmicaceous sandstones which contain many recrystallized grains, and some of which are nearly quartzitic in texture. Both the clays and sandstones commonly contain specimens of *Stigmaria*. The total thickness of the geologic section and the thickness and character of individual beds vary so much in such short distances that it is difficult to correlate the strata in adjoining exposures.

Most easily recognized is the Seville cyclical formation, in which occurs the Rock Island (number 1) coal, overlain in many exposures by dark blue-gray fossiliferous limestone and chert or siliceous shale (figure 3, *B*). In some exposures the Seville limestone is as much as 15 to 20 feet thick, whereas in others only a few hundred yards away it is absent.

South from the Rock Island region the earlier Pottsville strata are generally similar, but their thickness is gradually reduced (figure 3, *E* to *K*) to 35 feet in southern Fulton and northern Schuyler counties. Farther south, in a zone less than 2 miles wide in northern Brown County, all of the coals and limestones thin out, and a sandstone, probably the basal member of the Babylon cylical formation, overlain by several feet of light clay, is all that remains of the earlier Pottsville strata (figure 3, *N, O*). Still farther south (figure 3, *Q* to *T*) the sandstone is present only as thin and discontinuous lenses or is absent.

Later Pottsville Strata

The later Pottsville strata of western Illinois are best developed in Fulton and Knox counties (figure 3, *G* to *K*). These strata differ from the earlier Pottsville strata in that the members are more persistent, and dark-colored shales and limestones do not occur.

The persistence of thin members in the Pennsylvanian is nowhere better exemplified than in the "3 coal" zone of the DeLong cyclical formation, of which the following is the typical sequence:

	Thickness, inches
Coal	¼
Clay, brownish-gray	1½
Coal	¼
Clay, purplish-gray, sandy, grading into siltstone	9
Coal	1
Clay	15

This sequence has been recognized in exposures more than 50 miles apart. Similarly, the coal of the Seahorne cyclical formation is not more than 4 inches thick in any exposure studied, but it extends more than 100

miles north and south. The coal of the Wiley cyclical formation is equally extensive but ranges in thickness from 1 inch to 2 feet. The coal of the Greenbush cyclical formation is less persistent, reaching a maximum thickness of about 1 foot in Fulton and Knox counties and thinning out within 30 miles both north and south. The DeLong cyclical formation has the thickest underclay; the Seahorne cyclical formation has the only important marine limestone; the Wiley cyclical formation has the thickest coal; and the Greenbush cyclical formation has the thickest shale. The Greenbush shale is light gray to olive-gray and attains a thickness of more than 20 feet (figure 3, *A*) in Henry and Rock Island counties.

In northern Schuyler County the interval between the Colchester (number 2) coal (base of Carbondale series, and in Liverpool cyclical formation) and the Seahorne limestone decreases from 25 to 5 feet, and consists only of light gray underclay. The Seahorne limestone extends farther toward the southwest than any other bed of the upper Pottsville strata except the underclay. In Calhoun and Jersey counties its horizon is marked by light-colored pisolitic limestone nodules. Still farther west and south it is absent and the entire Pottsville series is represented by a light-colored, commonly refractory clay, the valuable Cheltenham clay of the Saint Louis region.

Earlier Carbondale Strata

The Liverpool cyclical formation includes strata of both the Pottsville and the Carbondale series and consists of (1) a basal sandstone (Isabel), (2) underclay, (3) coal (Colchester number 2), (4) gray clay shale (Francis Creek), (5) black laminated shale, (6) a fossiliferous succession of thin limestone and dark shale beds (Oak Grove member), and (7) thick clay shale (Purington). The Isabel sandstone differs from most of the earlier Pottsville sandstones and resembles the Carbondale and McLeansboro sandstones in being micaceous and feldspathic and in containing much ferruginous and locally much carbonaceous material. It was deposited on an erosional surface having a local relief of as much as 80 feet, and in parts of southern Fulton and northern Schuyler counties it rests on pre-Pennsylvanian strata. Coal number 2 and its underclay are present throughout the area studied and are known to be even more extensive. The Francis Creek shale reaches a thickness of 45 to 55 feet in central Fulton and McDonough counties (figure 4, *H* to *J*), thins to 5 to 10 feet in northern Fulton and southern Knox counties, and is absent farther north in Mercer County (figure 4, *C*). It also thins out to the

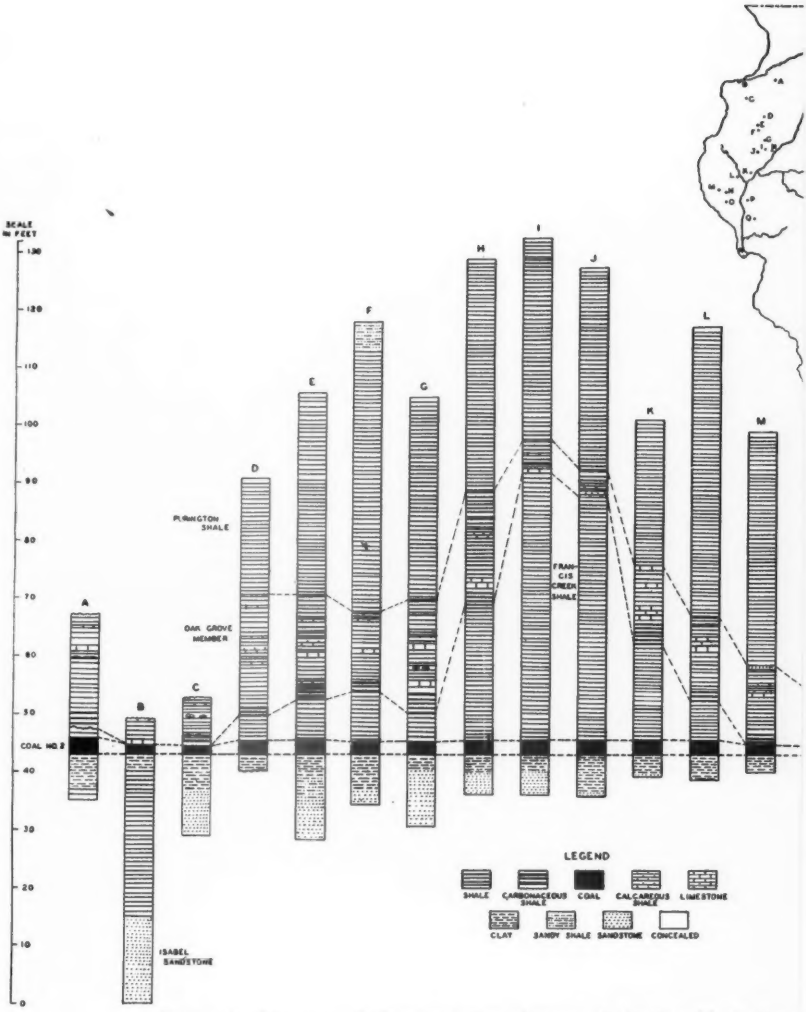


FIGURE 4.—*Diagrammatic Representation of measured stratigraphic Sections Carbondale Strata*

Showing the Liverpool cyclical formation, and the Isabel sandstone, numb
Francis Creek shale, Oak Grove limestone and shale. and Purington shale m

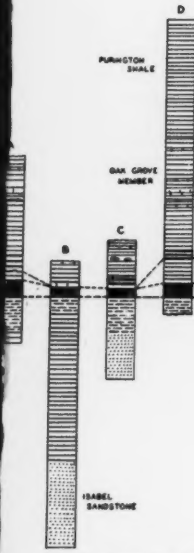
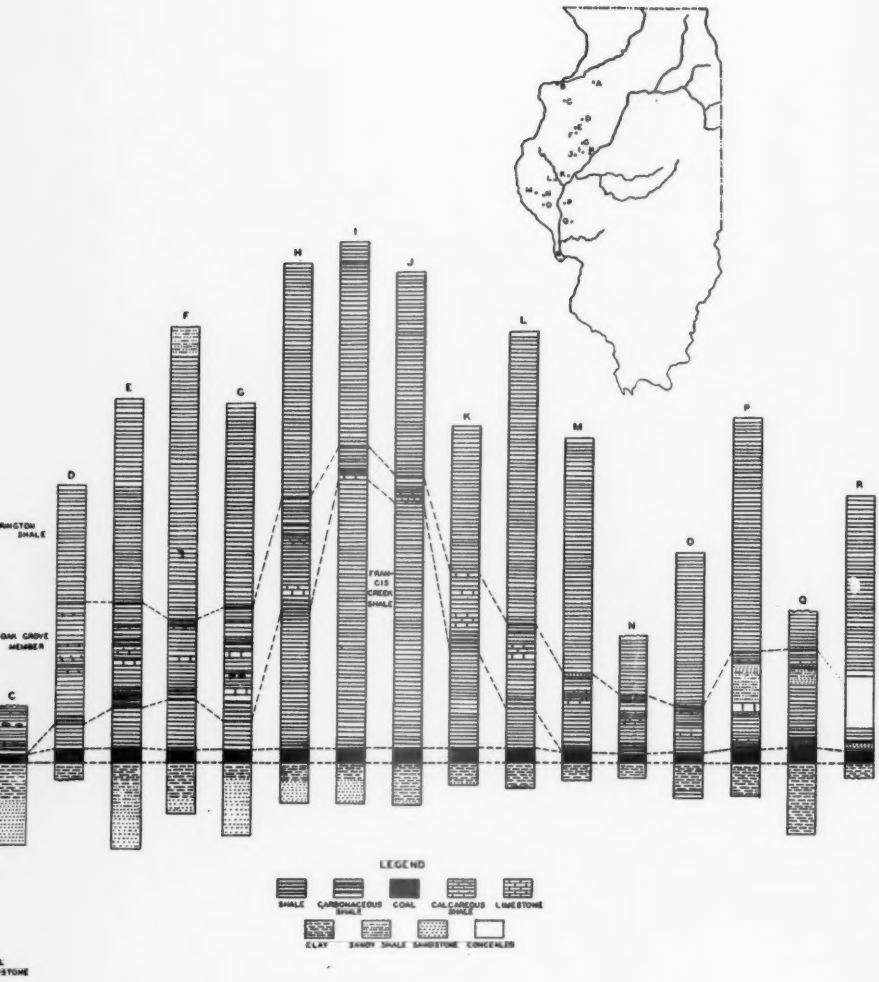


FIGURE 4.—*D*

Showing the
Francis Cr



URE 4.—*Diagrammatic Representation of measured stratigraphic Sections of earlier Carbondale Strata*

owing the Liverpool cyclical formation, and the Isabel sandstone, number 2 coal, Francis Creek shale, Oak Grove limestone and shale. and Purington shale members.

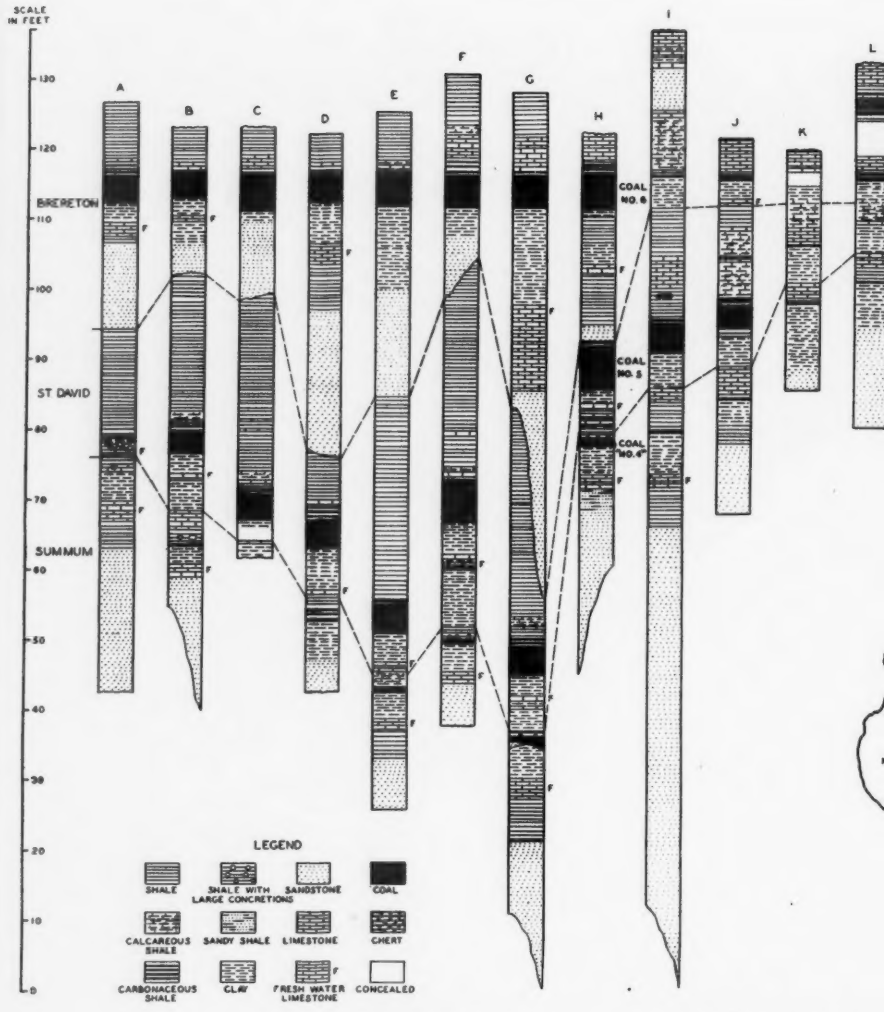
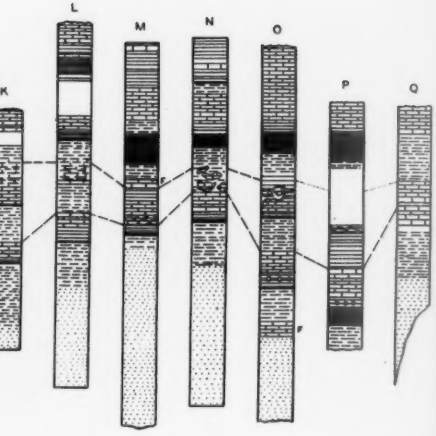
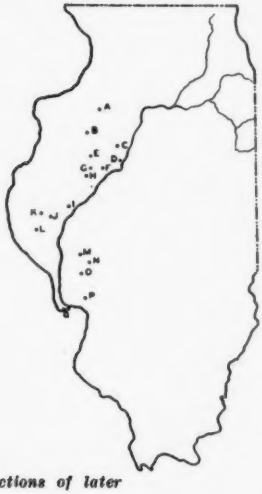


FIGURE 5.—*Diagrammatic Representation of measured stratigraphic Section*
Carbondale strata

Showing the Summum, Saint David, and Brereton cyclical formations, and
bers "4," 5, and 6.





hic Sections of later

ions, and coals num-

south (figure 4, *N* to *R*). Well-preserved leaves and stems of land vegetation were found in several exposures of this thick shale, and in a few places marine fossils were found.

The black laminated shale and the limestones and shales of the Oak Grove member are the best horizon markers in the entire Pennsylvanian system in western Illinois. The individual limestone and shale layers differ in lithology and in fossil fauna, and each bed of the section may be seen in scores of outcrops from Rock Island County on the north to Scott and Pike counties on the south. Southward and westward some beds become more sandy and grade laterally into fine-grained, fossiliferous sandstones in Green, Jersey, and Calhoun counties and in northern Adams County. This is the only instance in which limestones have been found to grade into sandstones and in which clastic sediments become more abundant toward the southwest.

The Purington shale extends from Henry County on the northeast to Calhoun County on the southwest without conspicuous change in lithology or in thickness. The color is commonly gray, but in Calhoun County and parts of Adams County it is reddish or reddish mottled with green. An important unconformity occurs above the Purington shale.

Later Carbondale Strata

The upper Carbondale strata include coals numbers "4," 5, and 6, and the associated strata. No basal sandstone occurs in the Saint David cyclical formation, but conspicuous unconformities occur below the basal sandstones of the Summum and Brereton cyclical formations. The "Summum" sandstone locally truncates all strata down to the Colchester (number 2) coal of which it forms the roof.[5] In the Peoria region the "Brereton" sandstone cuts out all strata above and locally truncates the Springfield (number 5) coal.[6]

The coals of the upper Carbondale strata differ in distribution. "No. 4"[7] coal, known to extend from Knox County to Jersey County, is a very thin coal bed, but it locally thickens to 2 to 6 feet where it occurs in basins eroded in underlying strata. Coal number 5 is a very uniform bed 5 to 6 feet thick in Fulton, Peoria, Schuyler, Sangamon, and Menard counties,

[5] A map of the drainage courses of this channel sandstone has been prepared. Sidney E. Ekblaw: Channel deposits of the Pleasantview sandstone in western Illinois. Illinois State Acad. Sci., vol. 23, 1931, pp. 391-399.

[6] G. T. Cady: Coal resources of District IV. Illinois State Geol. Survey, Coop. Min. Ser. Bull. 26, 1921, figs. 21 and 22.

[7] This is not Worthen's number 4 coal, described in his report on Fulton County, which was later shown to be the same as his number 5 coal, but a lower bed not noted in Worthen's section.

but it thins to the north and west to such an extent that it is absent in southern Henry, Brown, Morgan, Greene, and Jersey counties. Coal number 6 is a benched coal containing the well-known "blue band" and one or more other clay partings. It is 5 to 6 feet thick in Peoria, Fulton, Knox, Henry, and Bureau counties, and extends several miles farther southwest than the underlying number 5 coal, but is absent in Schuyler and Calhoun counties. Where the coal is absent, in Brown and Adams counties, the "blue band" persists in normal thickness between black streaks of carbonaceous clay.

The marine limestones all thin to the northeast and commonly become more shaly and less persistent in Knox, Peoria, and Henry counties. Throughout western Illinois the limestone over coal "number 4" contains dark-colored limestone pebbles and grades into a limestone conglomerate in Henry County. The Saint David limestone over coal number 5 consists of discontinuous limestone nodules in Peoria and Knox counties, a single massive bed in Fulton County, a chert stratum in parts of Jersey and Morgan counties, and a very irregular nodular limestone, containing heads of the coral *Chaetetes,* in Green, Macoupin, and Calhoun counties. The Brereton limestone over coal number 6 is shaly and discontinuous in Knox, Henry, and Bureau counties, but thickens and becomes less argillaceous southward and is persistent in the area south of Sangamon River.

The "fresh-water" limestones, which are commonly argillaceous and nodular, occur at or near the base of the calcareous portion of the underclay. They are most typically developed in Fulton, Knox, and Peoria counties, and are absent in Brown, Green, Jersey, and Calhoun counties.

The thicker clastic strata, especially the shale and sandstone between coals numbers 5 and 6, are absent in the west and south.

A group of beds which record a sedimentary cycle not represented north and west of Illinois River overlies the Brereton limestone in Menard County and extends southward to Jersey County. The sequence consists of (1) underclay, (2) coal, (3) dark shale, (4) limestone, and (5) gray shale. No geographic name has been applied to this cyclical formation.

Older McLeansboro Strata

The Sparland cyclical formation consists of (1) sandstone, (2) underclay, (3) coal (number 7), (4) dark shale, (5) limestone (Piasa), and (6) shale. The sandstone is rather thin throughout western Illinois. It rests on an erosional surface having a local relief of 10 feet or less. It thins to the southwest and is probably absent in Jersey County. The

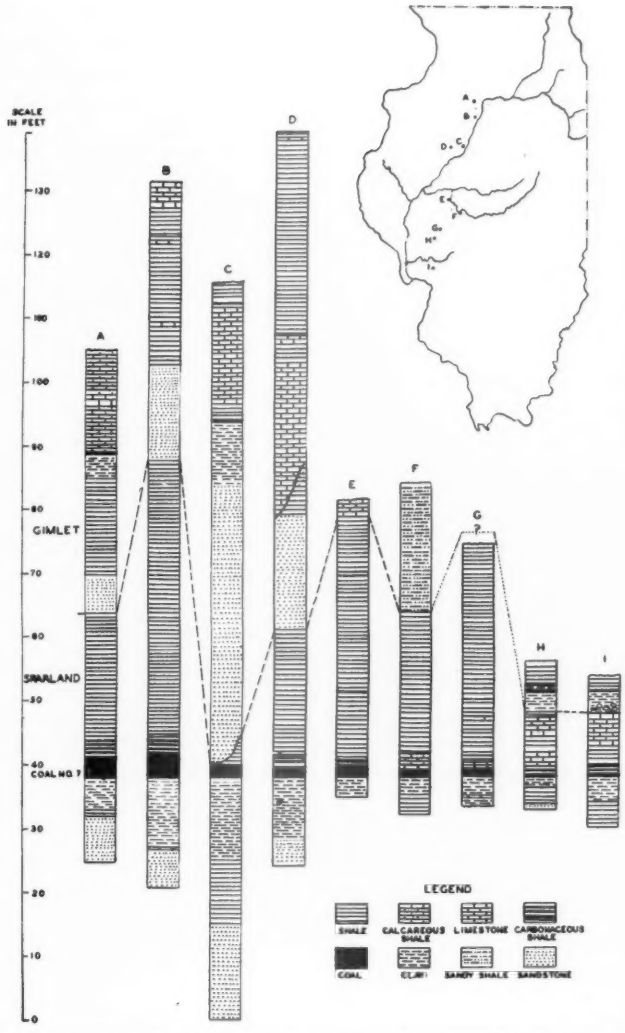


FIGURE 6.—*Diagrammatic Representation of measured stratigraphic Sections of older McLeansboro strata*
Showing the Sparland and Gimlet formations, and the number 7 coal member.

underclay attains a maximum thickness of about 25 feet in Peoria County, but thins notably to both the north and the south. The coal is 3 to 4 feet thick in Marshall County but thins to 1½ feet in Peoria County, 6 inches in Menard County, 2 inches in Sangamon County, and a coaly streak in Macoupin and Jersey counties (figure 6, *B* to *I*). The Piasa limestone is 5 feet thick in Jersey County but thins northward to 3 inches in Sangamon County, beyond which it has not been observed. The upper shale is more than 40 feet thick in Bureau and Marshall counties and is present in considerable thickness as far south as southern Morgan County, beyond which it thins out (figure 6, *G*, *H*).

The Gimlet cyclical formation in Peoria and Marshall counties (figure 6, *A* to *D*) is very different from that in Macoupin County (figure 6, *H*, *I*). The limestone (Lonsdale) member consists of one or several nodular beds separated by shale, so that it varies lithologically from a well-bedded nearly pure limestone to a mass of nodules in clay, and ranges from 1 to 20 feet in thickness in Peoria and Marshall counties. At some places in Peoria County it contains silicified wood, and a black phase in the upper part contains well-preserved leaf impressions. The Lonsdale limestone has not been observed south of Menard County. In Macoupin County the Gimlet cyclical formation is represented by (1) a fresh-water limestone, (2) clay, (3) a coal streak, and (4) a few feet of shale.

Younger McLeansboro Strata

These strata have been studied only from exposures in Sangamon and Macoupin counties, except for a small outlier of the Trivoli cyclical formation in Peoria County. The Shoal Creek cyclical formation and subjacent beds have been observed at only one locality, near Carlinville, Macoupin County.

The Trivoli cyclical formation consists of (1) sandstone, (2) underclay, (3) coal (No. 8), (4) dark shale, (5) limestone, and (6) gray shale. These strata persist through most of the region studied, but the limestone is not present in northern Macoupin County. The sandstone thins toward the southwest from more than 30 feet (figure 7, *B*) to 3 feet (figure 7, *E*).

The Carlinville cyclical formation consists of (1) sandstone, (2) shale, (3) limestone and (4) shale. One inch of coal occurs locally in the upper part of the shale below the limestone and the associated layers of shale contain abundant leaves and stems. Near Carlinville (figure 7, *F*) the limestone consists of two beds separated by about 8 inches of black

laminated shale.[8] The lower bed of the limestone is absent and the upper bed thins toward the north.

The strata above the Carlinville formation comprise (1) sandstone and (2) massive impure limestone overlain by nodular limestone (figure 7, *F*). These strata may record a cycle of sedimentation, and are tentatively so interpreted, but no geographic name is applied to the cyclical formation. The members thin out northward and only a nodular limestone extends into Sangamon County (figure 7, *C, D*).

In Macoupin County the Macoupin cyclical formation consists of (1) sandstone, (2) underclay, (3) coal (number 9), (4) dark shale, (5) calcareous shale, (6) limestone, and (7) gray shale. Northward the coal and

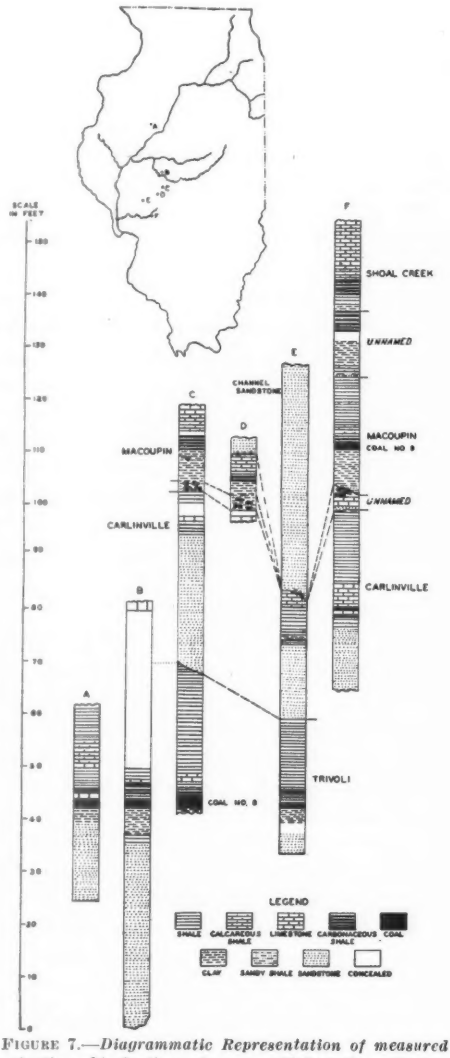


FIGURE 7.—*Diagrammatic Representation of measured stratigraphic Sections of younger McLeansboro Strata*

Showing strata from the Trivoli, Carlinville, Macoupin, and Shoal Creek and two unnamed cyclical formations, the number 8 and number 9 coal members, and a channel sandstone of undetermined stratigraphic position.

[8] This sequence of two limestones separated by black shale resembles rather closely the upper two beds of the limestone cycle described from the upper Pennsylvanian of Kansas. R. C. Moore: Sedimentation cycles in the Pennsylvanian of the northern midcontinent region (abstract). Bull. Geol. Soc. Amer., vol. 41, no. 1, 1930, pp. 51-52.

sandstone thin out and the limestone thickens from about 6 inches to 4 feet in Sangamon County (figure 7, *C, D, F*), a development opposite to that of the Carlinville limestone in the same series of outcrops.

Above the Macoupin cyclical formation occur (1) sandstone, (2) underclay, (3) coal, (4) dark shale, and (5) limestone interbedded with shale. No geographic name has been applied to this cyclical formation, which has been observed in only one outcrop.

The Shoal Creek cyclical formation consists of (1) clay, (2) coal, (3) black laminated shale and (4) limestone. The regional variation of these beds has not been studied.

A channel sandstone that is probably younger than the Shoal Creek cyclical formation cuts out the Macoupin and Carlinville formations in northern Macoupin County (figure 7, *D, E*). Another channel sandstone, the position of which in the section is undetermined, is exposed along the western margin of the coal basin from Adams County north to Muscatine County, Iowa, truncating Pennsylvanian strata of various ages. This sandstone is known to be younger than the Sparland cyclical formation and may be of the same age as the sandstone in northern Macoupin County. At some places it rests on pre-Pennsylvanian strata, indicating that its deposition followed an important erosion interval.

Summary

Field studies have shown that the Pennsylvanian system in western Illinois consists of a complex sequence of generally thin beds, most of which are persistent over large areas and nearly all of which can be definitely placed in a standard stratigraphic section. Each bed shows regional variations in thickness and lithologic character. No two beds follow exactly the same plan of regional variation, although most of the clastic beds thin and most of the limestones thicken and become purer toward the southwest. In the Oak Grove member of the Liverpool cyclical formation, however, limestones and shales grade into sandstones toward the southwest and thee Lonsdale and Macoupin limestones thicken toward the north. The importance of noting every change in lithology in every outcrop has been clearly demonstrated.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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SIZE OF BATHOLITHS[1]

BY ALFRED C. LANE

(Read before the Geological Society December 29, 1930)

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CONVENTIONAL SECTIONS AND MAPS

In cross-sections showing granite batholiths,[2] it is customary to depict them as extending down as far as the section goes, bounded by rather steep sides and with no known bottom, which is in accord with the definition of a batholith, but the question may be asked; how far is this due to those limitations of drawing which compel us, in showing what we know, to show also more than we know?

We find on geologic maps very large areas of a single color which indicate granite batholiths. If these were indeed all uniform granite they might be conceived as extensive, flat-lying sills of which only the top had been exposed by erosion, but it would be equally natural, indeed almost compulsory, to conceive them as sections of a uniform layer of granite "sial," supposed to underlie the continents and transmit earthquake waves with a velocity of 5.6 kilometers per second,[3] which had bulged up and been exposed at the surface. This layer H. Jeffreys[4] believes to be only

[1] Manuscript received by the Secretary of the Society January 6, 1931.
[2] For example, Am. Inst. Min. & Metal. Eng. Tech. Pub. 63, 1928.
[3] Compare R. A. Daly, Bull. Seis. Soc. Am., vol. 20, 1930, pp. 43-46.
[4] The Earth, second edition, 1929, p. 116.

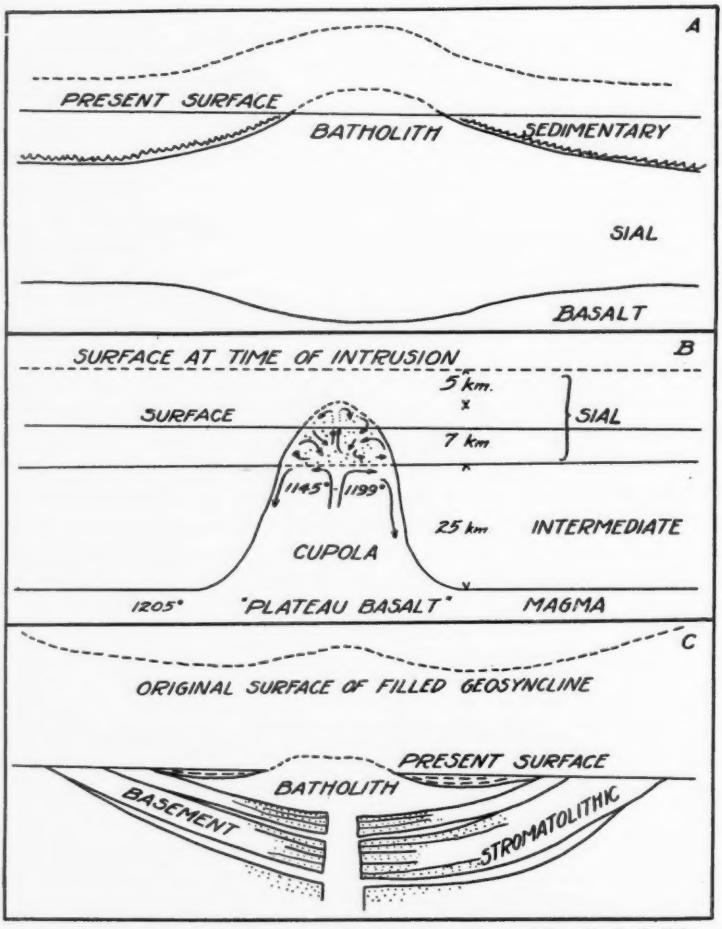

FIGURE 1.—*Diagram illustrating Three different Conceptions of Granite Batholiths.*

A, as an upbulge of a sial layer. Compare the figures (for example figure 8) in A. Holmes' "Earth movements," Transactions of the Geological Society of Glasgow, volume 18, part 3, 1929, page 575-593; also the Vredeport granite, page 8-9 and figure 20, page 149, of "The Vredeport mountain land," by Hall and Molengraaff, Shaler Memorial Series, Royal Academy Science, Amsterdam, 1925.

B, as a cupola, of fusion in part, such as is illustrated in figures 1 to 4 of Holmes' "Association of acid and basic rocks in central complexes," Geological Magazine, volume 68, June, 1931, pages 241-254.

C, as an intrusion on the surface which separates in a geosyncline the part compressed and ready to bulge up from that suffering tension and most subject to "stromatolithic" lit-par-lit injection: this upper part may be less compacted and therefore lighter and more flexible as well.

some 10 kilometers (about 6 miles) thick. The question may also be asked, Are batholiths so depicted because the scale is too small to bring out the way in which they are larded with bands of other rocks, through lit-par-lit injection? Quirke,[5] in describing the structure of the French River area, remarks:

> "Within these country gneisses certain areas have been mapped . . . as plutonic rocks, nepheline syenite, diorite and granite, but the larger scale manuscript map on which the field work has been compiled shows many more subdivisions. The masses of plutonic rock are in general small, less than 15 miles long and less than five miles wide."

He goes on to say that many thousands of feet, perhaps as much as 5 miles, of overlying rock have been eroded. This French River area accordingly appears to contain plutonic masses of much more than the usual depth of solidification. In this connection I would call special attention to Foye's[6] discussion of the nearby Bancroft area. His paper, together with a discussion in which the author participated during the winter of 1928, raised again the fundamental question: Just what are batholiths? I am inclined to agree with Foye that the word has been widely used where such words as "mass" or "area" might have sufficed, and that either its denotation or its connotation may need changing. In Kayser's Lehrbuch der Geologie[7] we find this definition: "Batholiths are closely connected with eruptive stocks and are distinguished from them by markedly greater size as well as by the fact that they have no bottom." They go down in "ewige Teufe" (E. Suess); they form "bottomless injections" (Daly). Kayser's illustration opposite the page cited in footnote 7 shows a batholith some 20 kilometers in diameter. Obviously, if this is not to be taken as the exposed top of a flat-lying sill or phacolith, and if we really suppose the contact slopes out in all directions, it must run down (figure 1, *A*) into the continuous granite layer which Jeffreys and others say transmits the earthquake waves for the first 10 kilometers of the earth's crust.

That has been the author's opinion for the past, but now he is not so sure. As a result of the presentation of this paper in Toronto a number of geologists discussed the subject, and the consensus of opinion was that with the exception of the Coast Range granodiorite of California to the British Columbia granite, masses of uniform grain are generally of no great dimensions. Like the Adirondack granites referred to by New-

[5] Jour. Geol., vol. 37, 1929, p. 687.

[6] "Are the 'Batholiths' of the Haliburton-Bancroft area, Ontario, correctly named?" Jour. Geol., vol. 24, 1916, pp. 783-792.

[7] Sixth edition, 1921, vol. 1, part 1, p. 221.

land at the same meeting in his paper "Structures in Adirondack magnetites," they have followed the planes of bedding and were intruded as a series of sills. The work of Balk and Buddington in Bulletin 281 of the New York State Museum points to a phacolithic rather than a batholithic form. On March 26, 1931, J. A. Dresser discussed the matter before the Royal Society of Canada.

Seismic Evidence

It may be asked: Does not the evidence of the seismograph point conclusively to a granitic layer at a relatively shallow depth? It has been so interpreted.[8] Yet in many localities the geologist may reasonably infer a structure due to the folding of various kinds of sedimentary rocks extending downward far more than 6 miles. As there are plain indications of broad folds extending high in the air; we can not but think of comparable down-folds. Heim,[9] in one of his most recent sections of the Alps, concludes that the depth of folding is from twenty to thirty times the mean height of the mountains. There can not then be a continuous layer of granite at a shallow depth under them, and Heim's figure does not indicate such a layer. We may then ask ourselves whether the velocity of propagation of the first earthquake waves (P_g) would not be the same in a series of compacted rocks which have been stewed in granitic syrup as it would be in granite itself (5.5 kilometers a second). Jeffreys, in his figures, leaves but scant room for any sedimentary rocks.

The granitic rock of the seismologists and the "Upper layer of 'granitic composition' " of Holmes' figures [10] must then be understood to include gneiss and metamorphosed sediments—granitized rocks (figure 1, *B*).

Gravity Evidence

In discussing the bearing of theories of isostasy—and the author accepts the principle—it should be emphasized that the pendulum and Eötvös balance give no evidence as to the weight of concentric shells of the earth so long as they are uniform over the earth. They only show the differences from the value normal to a given latitude and elevation. They can and do show that the weight of the layer under the sea-floor is different from the weight of that under the continents—different enough nearly to counterbalance the fact that there is only some two or three

[8] H. Jeffreys: The earth, second edition, 1929, p. 100 and chapter VI, especially §s 6, 7.

[9] Jubilee Volume of the Belgian Geol. Soc., 1874-1924, vol. 1, part 1, pp. 16-26, especially p. 26 and fig. 4.

[10] Geol. Mag., June 1931, p. 144, fig. 1 and passim.

miles in depth of water above them, while under the continent at a similar depth there is on the average half a mile more of rock, which would be two or three times as heavy, but they do not show what the actual weights are. Hayford and Bowie [11] assumed that the difference in weight was uniformly distributed through a layer under each point, and found that, considering the whole United States, values for gravity better agreeing with those observed would be found by taking the layer 57 kilometers thick,[12] while for mountainous regions 110 kilometers gave better results. But although they found that these assumptions gave results sufficiently exact for the needs of the Geodetic Survey, with errors within the range of instrumental error, Hayford and Bowie did not say that they were geologically accurate (page 8).

G. P. Putnam's conception of regional balance [13] is more likely, and as appears from Bowie's work,[14] the effect of the pressure of a mountain may be distributed over a circle of about 58 kilometers radius. Moreover, geodetic work shows merely that the load differences or anomalies in gravity at different points can be accounted for by differences in density of the material beneath these points, the center of gravity of the differences being about one half of 57 kilometers down.

If we assume that the isostatic adjustment is obtained by the depression of a lighter layer with a heavier layer as Airy suggested, then this uneven bottom of the lower layer (figure 1, *A*) would be from 25 to 60 kilometers down. The difference between the two theories of isostatic adjustment might be illustrated by considering the unevenness of the crust of the earth, on the one hand, as comparable to the unevenness of a raft of logs of pine and oak all submerged to the same depth but projecting above the water in different amounts, and on the other hand as comparable to a raft of logs of pine of different sizes projecting both up and down.

Evidence of Grain Size

There is, then, no coercive evidence of a layer of crystallized granite "sial" beneath the outer sediments, though the seismic and gravity evidence indicate a layer which may be formed by a thickening of sediments metamorphosed and granitized.

The author wishes particularly to call attention to another kind of evidence, namely, the grain size. In any igneous rock the coarseness of

[11] U. S. Coast and Geodetic Survey publications, especially No. 40, which refers to the earlier ones.

[12] Loc. cit., figure 5.

[13] Nature, March 2, 1929, p. 316.

[14] Publ. 40, p. 91.

the grain, other things being equal and assuming that we are not dealing with a granulation due to crushing, increases with the slowness of the crystallization. In the interior of a large cooling mass, the slowness increases with the size of the mass.

In working out the theory of the coarseness of grain as affected by the rate of diffusion (of heat or of mineralizers) which the author developed in 1894-1896,[15] and which is abstracted in E. E. Fairbanks' recent book,[16] the author found that theoretically there should be a central belt of uniform cooling and even grain, in which the size of grain (E) did not vary with the distance from the margin. For the even grain (E) the author obtained the formula

$$E = \frac{kc}{\pi a \sqrt{u}}$$

That is, the average linear dimension of the grains (of any ore mineral thus formed) (E) increases proportionally to the "power of crystallization," which depends on the composition, etcetera, (k), and to the linear scale of the phenomena, for example, the thickness of an intrusive sheet and its contact zone (c), but decreases with the square root of the diffusivity (a^2) and the difference between the conditions (temperature and/or in content of mineralizer) at which crystallization takes place and those of the country rock (u). The initial conditions of the magma are not a factor, as they are in any marginal zone of varying grain.

In small aplite dikes the grain is fine because (c) is small, but in the pegmatites we may find extremely coarse grain because (u) is small and also because of a continuous slow supply of hot material.

Although the above formula is derived for the ideal condition of an infinite sill with parallel walls symmetrically cooling, the author has shown how it might be modified to fit unsymmetrical cooling and other irregularities. B. O. Peiree[17] has also contributed to the theory, showing that the temperatures on the curved surface of a cylinder make little difference to the axial temperatures if the radius is five times the height.

The theoretical consideration that there is a belt of even grain is important, as it agrees with experience. The fact that if the grain is uniform the initial conditions of the magma are not important but only the gap between the conditions of crystallization and those toward which the diffusion of heat and mineralizers takes place, is not at first sight obvious; but that the cooling should be slower and the grain coarser if this gap

[15] Bull. Geol. Soc. Am., vol. 8, 1897, p. 403; also vol. 14, 1903, pp. 394-395.
[16] Laboratory investigation of ores, chapter VI, p. 123.
[17] Am. Assoc. Arts and Sciences, vol. 45, Apr., 1910, pp. 353-360.

is not great or if the conductivity of the material is not large, accords with common sense, as does the indication of the formula that the larger the mass and the greater its crystallizing power, the coarser will be the grain. The crystallizing power is naturally low in viscous glasses and high in metals.

GRAIN SIZE IN GRANITE

The object of this paper is to stimulate the author's colleagues to apply this formula to granites. The diameter of a nonporphyritic grain of granite is not more than one centimeter, usually about 8 millimeters. That grain size may put a limit on the size of granite bodies, and this in turn will lead us either to curtail our use of the term batholith or to modify our definition as Dresser suggests.

The exact conditions of crystallization, of course, vary for feldspar and for quartz; but in a hypidiomorphic texture they are so nearly contemporaneous and equal in size as to warrant in this preliminary study grouping them together.

The formula above we may write

$$E/c = k/\pi a\sqrt{u}$$

and if the last member is fixed, or varies only within limits, then E determines c within the same limits.

The diffusivity of granite (a^2) is in C. G. S. units[18] about 0.0131 at the surface. Even at 10 kilometer depth, therefore, (a^2) can hardly be over 0.12 and, from what we know of diffusivities, will lie between 0.12 and 0.07.

The excess of temperature (u), judging from the "geological thermometer," quartz, can hardly be much over 900° Centigrade,[19] minus the temperature of the surrounding rock, so that its square root may be taken at less than 30. It is probably between 20 and 30.

The diffusivity of the mineralizing gases under these conditions the author knows little about. Without doubt they do expand and leave the magma, producing the well-known contact zone; they accelerate the formation of, and thus make finer, the grain of the granite. However, it is clear that the deeper the burial the greater will be the pressure and, in consequence, the slower the diffusion of the gas. Also, the deeper the burial the greater will be the temperature of the country rock above, and especially below the sill of granite. Both of these factors will tend to retard the cooling as compared with more superficial intrusions, and to

[18] International critical tables, vol. 2, pp. 313-316.
[19] R. A. Daly: Bull. Seis. Soc. Am., vol. 20, 1930, p. 48.

make the grain coarser. Consequently, the grain should be coarser rather than finer in larger and deeper seated bodies than in cases near the surface.

Thus we have, letting π be 22/7

$$E/c = k/\pi \text{ (0.07 to 0.12) (20 to 30)} = k/6.6.$$

For certain places where we know E and c we can compute k. For instance, in a dike of granite from the Utah Apex region, cores of which were sent the author by J. Carter Anderson, $c/E = 6850$ centimeters/(.1 to .3 millimeter) = 68,500 to 22,833.

In the Clinton granite dike, well exposed in a long tunnel of the Boston Metropolitan Waterworks, leading from the Clinton reservoir

$$c/E = \frac{56{,}300}{0.8} = 70{,}000$$

though here there were also porphyritic crystals of feldspar 5 to 8 centimeters long. Probably u and a are not quite the same in these examples; but assuming them to be the same, we get values of $k = 0.00014$ to 0.00003. At that rate a sheet of crystallized granite 10 kilometers thick ought to have a grain of some 30 centimeters or more. The big 3-inch porphyritic crystals in porphyritic granites might well be intratelluric, but not the ordinary hypidiomorphic grain.

What Foye [20] calls stromatolithic granite, that is, lit-par-lit, is sometimes quite coarse even though the sills are thin. This may be explained by saying that the country rock was close to fusion or solution with mineralizer. In the larger masses of granite of uniform size one would have to look to one of the following assumptions for an explanation: the larger a granite mass the less gas it had, or the more rapidly gas had escaped before crystallization set it, or the higher up in the crust it was intruded and thus relatively in cooler country rock, so that u was greater (figure 1, C).

A letter just received from Prof. A. Holmes seems significant:

"My experience in Mozambique and knowledge of other areas like Finland by their literature suggest to me that batholiths can not be very deep, because no sign of them is to be found in the levels of the crust deeply denuded by long exposure and uplift. The rocks there are all gneisses, veined through and through with thin granitic veins."

[20] Loc. cit.

The big feldspar phenocrysts in granite, with nothing to correspond with them in quartz, would suggest (if they are really intratelluric brotocrysts and not rhyocrysts or oriocrysts formed—see figure 1, *B*—because of an excess of feldspar molecules) a deep-seated layer in which the feldspar was crystallizing but not the quartz.

Professor Koenigsberger writes: "I agree with you that batholiths are not bottomless. Magnetic observations make it probable." [21]

Other Factors of Grain Size

One must also consider whether the grain may not be one of devitrification. It seems to the author probable that spherulitic and perhaps also orbicular textures may be so regarded. But in the author's opinion to assume that a large mass of granite could get down in a glassy state well below the labile zone of crystallization and then be reheated, devitrified, and later uplifted so as to be exposed, requires too quick a transition through the labile zone and an unexplained mechanism for reheating. Radioactive heating should be continuous, should prevent the mass passing through the labile zone without crystallizing. The frictional heat of injection should, one would think, leave its traces in a protoclastic structure, and it is assumed that petrographic examination has ruled out such structures.

Finally, there is no clear reason why the grain produced by such "annealing," heating and cooling should not at least in some instances be very coarse. Indeed it seems to be. A trip in the summer of 1931, since the presentation of this paper, has enabled me to see in rapid succession granitic contacts of the Lake of the Woods in Canada, of the Coast Range batholith near Victoria, under the guidance of V. Dolmage and T. C. Chemister, and near Butte under the guidance of R. H. Sales and E. S. Perry, and the beautifully polished exposures used in the Planetarium building in Chicago.

It would seem that the Coast Range batholith may not be an exception as to the limitation of size. Also a granitic magma has a remarkable faculty for working into the country rock without entirely obliterating its original strike in such a hot, viscous, jellylike condition that it can crack, but has not its final crystallization. The margin of a granite may be thus crowded with fragments as though it had caused a decrepitation of the country rock, and the conditions of the whole mass close to those of crystallization, so that there is a strong tendency to irregular and pegmatitic grain.

[21] Personal letter, Dec. 16, 1930.

Large crystals may be due to crystallization out of ingredients in excess, and so may certain phenocrysts. But the limitation in the size of the quartz and feldspar phenocrysts in quartz porphyries and granite porphyrites points to a limitation in the size of the bodies in which they were formed.

Granites as anchieutectic Segregations

The limitation of ordinary granite grain to about 8 millimeters—and Daly, Larson, Laforge and others agree with the author that this is above the limit—would imply that it was in dikes, sills, stocks, or phacoliths of about one kilometer in thickness, or perhaps in series of stromalolithic lit-par-lit injections, no one member of which was more than one kilometer thick.

What the author would like to know is: In how many instances is granite demonstrably more than 300,000 times thicker than its grain? In the case of the Quincy granite, for instance, Billings states that geologists are now coming to believe it not more than a mile thick. In other words, it is not in the form illustrated by *A* of figure 1.

Such a form was suggested by Holmes as likely to be produced by continental drift and subsurface convection in the asthenosphere, and is one also suggested naturally by Airy's "roots of the mountains" theory of isostasy. The author thinks, however, that it is clear that a normal, even grained, hypidiomorphic granite is too fine grained to have its crystallization determined as a part of such a body. But if granites do not represent a great sheet of sial, the question is still open whether the granitic juice or magma is not being segregated and expressed from the basaltic layer (figure 1, *B*), a continuation of the series made by the micropegmatitic interstices in the quartz diabases [22] the red rocks of Mount Bohemia,[23] the Duluth gabbro,[24] the Nipissing diabases,[25] and the granites Dresser found to have been segregated from the serpentine.[26] We should also add "and/or" being formed by syntex is, as Daly has suggested, by the fusion or incorporation of siliceous rocks. This is the mode of origin which Holmes combines with that of convection in the formation of the cupolas of granite illustrated in figure 1, *B*.

However, a granite formed by syntexis (the author agrees with Holmes in thinking that such an origin is worth considering for the top of the

[22] Geol. Surv. Michigan, vol. 6, part 1, 1898, pp. 235-243.
[23] Geol. Surv. Michigan, Annual Report for 1908, pp. 355-402.
[24] F. F. Grout: Jour. Geol., vol. 18, pp. 633-657.
[25] N. L. Bowen: Jour. Geol., vol. 18, 1910, pp. 658-674.
[26] Reviewed by Lane in his article "Segregation granites," Jour. Geol., vol. 30, 1922, pp. 162-166.

Sudbury lopolith, as well as for the Moyie sills and the rocks of Pigeon Point, Minnesota) should tend to be pegmatitic and irregular in texture and grain, to have its original temperature not much above that of crystallization, and to be porphyritic with "liberated" crystals. Under this term Holmes would include both brotocrysts and rhyocrysts. There are such granites.

Must we not also consider another mode of formation of bodies (figure 1, *C*) that would appear as batholiths, bodies appearing in quasi-sills or laccoliths, that is phacoliths or chonoliths? Suppose we have part of the crust bent down in a geosyncline, tending thus to be stretched and crack in the lower part, and then invaded by granitic syrup or magma, which may spread out between the beds in lit-par-lit injection. At the some time the upper strata will be less compacted, therefore, lighter on the average. Probably, being less rigid, they will be more likely to yield and bulge. Near the surface that separates the tense part from the compressed, the granite may well invade and buckle up the part above. The surface appearance will be indistinguishable from figure 1, *A* or *B* but the actual section will be like *C*.

Being nearer the surface it will be in cooler rocks than the stromatolithic rocks and have less vapor pressure, k will be less and u greater and so it will be, for its thickness, fine grained. This level of no strain may well be at something like the same depth the world over. Thus we might account for the general agreement in the grain of granites.

Bearing on Radioactivity, Geotherms, etcetera

Obviously, if granite has been segregating at various times in geologic ages from a layer in which the radioactive elements are undergoing slow decay, and, as we know, at varying rates, the proportions of uranium and thorium with which it starts should be different and their later history should be different. If the contribution of radioactive disintegration to the generation of heat was not large in a thick layer of granite whose diffusivity was less than that of basalts, the geothermal gradient over it would be less; but, granite contains so much radioactive material that the gradient might well be higher. As Holmes points out[27] 11 kilometers of granite and 22 of basalt would furnish enough heat to give a gradient of 32° Centigrade per kilometer, probably more than is coming out, leaving no room for contributions of heat from the deeper parts of the earth. If, however, the sial layer is not granite (figure 1, *A*) but granitized sedimentaries (figure 1, *B* or *C*), the radioactivity is likely

[27] Loc. cit., p. 573.

to be much less and Holmes' numerical calculations must be seriously modified. There will be a marked difference according as we assume a structure like *A* or *B* or *C* of figure 1. *C* is such a structure as the author imagines may occur in the middle of a geosyncline where the rocks above the batholith are like the series that occupies the basin of lower Michigan and the batholith has split them off from the basement of metamorphic rocks. To take a concrete instance, the granodiorites which in the west invade the Mesozoic and even Tertiary, may be conceived to have split them off from a Precambrian basement. Their fine grain points that way. Obviously, much less could be inferred from the radioactivity and geothermal gradient in such rocks as to the average distribution of radioactive elements in the earth and its loss of heat.

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ALLUVIAL FAN OF POTOMAC RIVER[1]

BY MARIUS R. CAMPBELL

(Read before the Society December 29, 1930)

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GENERAL DESCRIPTION

When one travels southeastward from the Capitol at Washington he crosses Anacostia River and climbs a rather steep elevation known as Good Hope Hill. The western slope of this hill is composed of bedded deposits of Cretaceous and Tertiary ages, but the summit is capped by unconsolidated gravel and sand of a much younger formation. The gravel bed ranges in thickness from 20 to 40 feet and is composed largely of pebbles

[1] Published by permission of the Director of the United States Geological Survey. Manuscript received by the Secretary of the Society June 1, 1931.

and cobbles of vein quartz, quartzite and fossiliferous chert; and the sand associated with the gravel is generally well washed and pure, although in some places it is intermixed with clay in the form of lenses and irregular masses. Good Hope Hill has an altitude of about 300 feet, but instead of being an isolated knob, as one might suppose from the name, it is a small part of a much dissected plateau capped by the gravel referred to above. The Cretaceous rocks which crop out along the northwestern margin of the plateau dip toward the southeast and soon pass below Tertiary beds of Eocene and Miocene ages which form the basement of about nine-tenths of the plateau. These beds were laid down on the Continental Shelf, later uplifted and slightly tilted with relation to sealevel, planed off to a very smooth surface, and then covered with a veneer of gravel which is the subject of this paper.

The route usually followed in crossing this plateau is the Upper Marlboro highway, which at first curves decidedly toward the north, but in general pursues a course a little south of east. The width of the plateau is here about 10 miles, and beyond this limit the surface drops off irregularly to Patuxent River, which flows at tide-level in a drowned valley. Whether the plateau, as originally formed, was limited on the east by this valley, or the valley has since been incised in the plateau, can not be definitely stated at the present time, but, as will be explained later, there are some facts which indicate that Patuxent River at one time flowed southward on the surface of the plateau and later intrenched itself at the same time that Wicomico River and Piscataway, Matawoman, and Port Tobacco creeks—all flowing into the Potomac River—were engaged in deepening their valleys down to the level of the parent stream.

The Upper Marlboro highway follows a drainage divide between streams flowing southward into Potomac River and those flowing eastward into Patuxent River. Curiously enough, the plateau extends only a short distance north of this divide, and there breaks down in a ragged escarpment ranging from 100 to 150 feet in height. This divide is the highest land on the peninsula between Potomac and Patuxent rivers, and the most elevated point on it (300 feet) is where it crosses the southeastern boundary line of the District of Columbia. From this summit the surface slopes gradually to the south and east, reaching an altitude of about 270 feet just west of Upper Marlboro. The character of the gravel bed also changes in this direction. Instead of being composed mostly of gravel, as it is on Good Hope Hill and Henson Run, the pebbles are smaller as one goes toward the southeast and the amount of coarse material in the bed diminishes steadily to a point about 3 miles west of Upper

Marlboro, where the gravel practically disappears—apparently being replaced by sand.

Similar conditions prevail throughout the entire peninsula, except that the altitude of the surface gradually diminishes in a southerly direction, until it is down to a little below 100 feet at Ridge, just back of Point Lookout—the southernmost point of Maryland west of Chesapeake Bay. In this area the writer has not attempted to map the beds in detail, but sufficient exposures have been seen to suggest that the gravel does not cover the entire tract, but that there are two areas or streams of this material—one followed by the Washington–Leonardtown highway extending down the backbone of the peninsula from the northern extremity, as outlined above, parallel with Patuxent River on the east as far as Ridge, and the other branching off from this backbone ridge at the village of Brandywine and extending due south to the town of La Plata and the Potomac River. In both branches of this Y-shaped deposit, the gravel appears to be continuous and may be seen in almost every ravine cutting the gently sloping surface.

From this peculiar arrangement of the gravel, it seems obvious that it was deposited in two streams that divided near the village of Brandywine, from which the deposit takes its name. The area between the two branches appears to contain little gravel, but an abundance of sand which seemingly replaces the gravel on the margins of the two principal streams. A similar change from gravel to sand was noted at many points on the eastern side of the peninsula, generally a mile or so east of the Washington–Leonardtown highway. Although this line of change from gravel to sand was not mapped, it is thought to extend in an unbroken line from near Upper Marlboro to the mouth of Patuxent River, and, curiously enough, it is practically parallel with that stream.

The change from gravel to sand is not abrupt, but is generally accomplished by the thinning of the gravel bed or beds and the decrease in size of the pebbles from a maximum of 5 or 6 inches down to pebbles not greater than 1 inch in diameter and finally into clear sand. This change in an easterly direction was noted by William B. Clark,[2] who described it as follows:

"The gravels are chiefly developed on the landward portions of the formation and decline in frequency as well as in size of cobbles toward seaward portions of the formation and are almost entirely absent near the seaward [eastern] margin, being replaced altogether by sands and loams."

[2] The Brandywine formation of the Middle Atlantic Coastal Plain. Amer. Jour. Sci., 4th ser., vol. 40, 1915, p. 502.

It was also recognized by George B. Shattuck in his map of this region,[3] though he called it Sunderland formation and differentiated it from the "Lafayette" (gravel-bearing formation) lying 2 miles or so west of Patuxent River.

The writer has had no opportunity to study in detail the surficial formation between Patuxent River and Chesapeake Bay, but a reconnaissance trip on this peninsula from the mouth of Patuxent River to the latitude of Upper Marlboro showed that it also is covered with sand and loam, containing in places very small pebbles. This material is so similar to that which the writer has seen in abundance west of Patuxent River that he is strongly inclined to the belief that at some time in the past they have been united as one continuous deposit, lying wholly east of the regular gravel deposits herein described.

The difference in the protective value of gravel and sand as affecting erosion is well illustrated in this region. Thus the Y-shaped area of gravel, already described, is almost unbroken by stream valleys, whereas the area between the two limbs of the Y offered less resistance and as a consequence Wicomico River and its tributaries have cut deep channels into its original surface and Patuxent River found the easiest route to the Bay down the eastern margin of the gravel belt, where the protective cap of gravel gives way to a less efficient cap of sand and loam.

The writer has not been able to follow the gravel formation in detail southward beyond Potomac River, but in a reconnaissance examination he found a thin bed of fossiliferous Devonian chert pebbles at an altitude of about 100 feet in Red Hill 2 miles west of Warsaw, Virginia. The source of the gravel is in the belt of folded rocks northwest of the Valley of Virginia, and from that location the material could have been brought to its present resting place only by Potomac River on the north or by James River on the south. As all of the data at hand point clearly to the southward transportation of surficial material on this part of the Coastal Plain, it seems almost certain that Potomac River was the agent by which the chert was carried to its present resting place in Virginia, despite the fact that today this locality is considerably beyond the southern limit of the drainage basin of this river. How much farther southward such material was transported is not known, but since it has undoubtedly reached the vicinity of Warsaw, it is quite possible that it may have extended nearly to the mouth of Rappahannock River.

[3] Pliocene and Pleistocene. Geol. Survey of Maryland, 1906, pl. 1.

Features of Importance

From the data that have been given in this brief sketch and from the map shown in figure 1, it is evident that here is a large, rudely triangular, sloping plateau covered with gravel and sand, which spreads out fan-shaped from an apex just east of Washington to a width of 40 miles in the vicinity of Leonardtown, Maryland, and which extends southward at least as far as Warsaw, Virginia, a distance of 65 miles. This area was doubtless once covered with an almost continuous sheet of gravel or sand, which is thickest at the apex of the fan and grows thinner and the material composing it finer and finer from this point southward as far as it has been traced. From the distribution of the material it is evident that about 15 miles south of the apex the coarse material divided into two streams, the westernmost of which extended no farther than Potomac River in its great southwestward bend about 30 miles from the apex, whereas the eastern stream extended to the Potomac at Ridge and thence southward at least to Warsaw on the bluffs of Rappahannock River. Also that these streams of gravel are bordered, especially on the east, by belts of sand, in places as much as 10 miles in width, which appear to be outwash material from the principal deposits of gravel.

In considering the origin of this deposit there are three very significant phases of it which should receive careful attention and study, as follows: (1) The gradual southward slope of the deposit, which is approximately parallel with the slope of the formations of the Coastal Plain on which it rests, from an altitude of 300 feet on Good Hope Hill, just east of Anacostia, to about 100 feet at Ridge, Maryland, near the mouth of Potomac River, and the same altitude at Warsaw, Virginia, on Rappahannock River. The slope of the surface is regular, barring minor inequalities which probably are due to comparatively recent stream erosion; (2) the variation in the coarseness of the surficial material and the distribution of the coarse and fine deposits; (3) the abrupt north-facing escarpment which limits the gravel east of Washington and separates the relatively high plateau on the south from a region of low relief on the north. This low area ranges in altitude from sealevel to 150 feet and extends from the District of Columbia northeastward to and beyond the city of Baltimore. As far as the writer is aware, no one has recognized the unusual character of this scarp, and consequently no effort has been made to interpret its meaning. Most statements on the subject are to the effect that north of the District line the gravel has been eroded and its removal has left the plateau without the protection necessary to maintain its original altitude. The present writer, however, can not

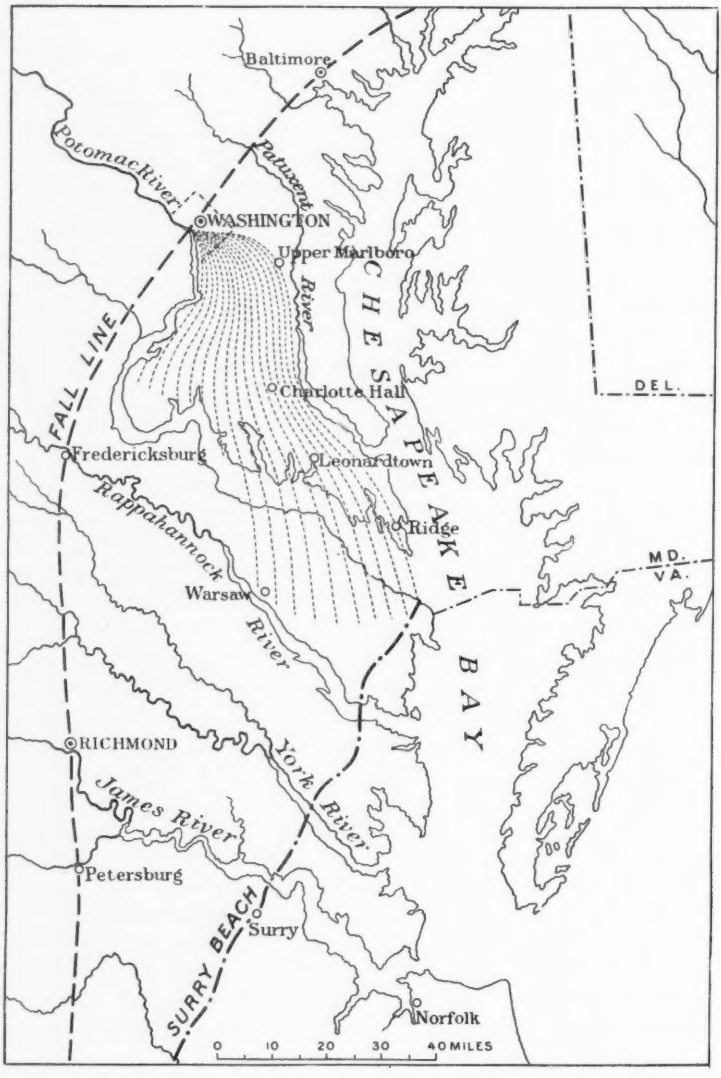

FIGURE 1.—*Outline Map of Region between Baltimore and Norfolk*

Showing the position and known extent of the alluvial fan of Potomac River together with its relation to the Fall Line and the Surry abandoned beach.

agree with this view of the case because gravel is one of the most efficient protective caps and one of the most difficult to remove that is known to geologists, and the marked reduction in the height of the plateau along a definite line very probably means, not that the gravel cap north of this line has been removed, but that originally this line marked the northern limit of the cap. If this be true, then the problem narrows down to accounting for the deposition of a rudely triangular, or rather, fan-shaped deposit of gravel which at a distance of about 15 miles from its apex divides into two prongs, the easternmost of which extends at least as far as Rappahannock River near Warsaw, Virginia, and to accounting for a marginal deposit of sand which on the east extends to Chesapeake Bay and on the west occupies the area between the two streams of gravel, as previously described.

Conclusions of previous Workers

As this is a region that has been examined in the past by a number of leading American geologists, it is desirable to review briefly the results of their work before attempting to present the writer's explanation of the phenomena in question. The present knowledge regarding this portion of the Atlantic Coastal Plain rests mainly upon the work of three geologists—W J McGee, N. H. Darton and G. B. Shattuck. Apparently McGee was the first to propose definitely a mode of origin for the gravel deposits of the Coastal Plain.[4] His explanation follows:

"The Columbia formation has been studied in and traced over the Middle Atlantic Coastal Plain. It consists (1) of a series of deltas laid down along the inland margin of the coastal plain by the Middle Atlantic slope rivers—the Roanoke, the Appomattox, the James, the South Anna, the North Anna, the Rappahannock, the Potomac, the Patuxent, the Patapsco, the Susquehanna, the Brandywine, the Schuylkill and the Delaware—during a period of submergence reaching fully 100 feet at the first-named river, about 450 feet at the last named, and intermediate amounts at the intermediate rivers; and (2) a series of terraced littoral deposits connecting and graduating into the deltas and covering the remainder of the coastal plain to the Atlantic Ocean. The deltas alike consist of a lower division made up of boulders, coarse gravel and sand, and an upper division made up of brickclay or loam; but this bipartition is the less definite in the littoral phase of the formation."

As McGee had not differentiated the Columbia from the more ancient gravels of the Coastal Plain, it is a fair inference that he included in the delta deposits all of the material here being considered. To the gravel on the Piedmont, McGee gave the name "Appomattox," but later

[4] The Columbia formation. Amer. Assoc. Adv. Sci., vol 36, 1887, p. 221.

changed this to "Lafayette." Both of these names have been used in various papers dealing with the deposits here described. Still later the name "Lafayette" was found to be inappropriate for the older surficial formation of the Coastal Plain of southern Maryland and William B. Clark in 1915 proposed the name Brandywine,[5] as follows:

"The recognition by the U. S. Geological Survey and the various State Surveys in the Atlantic border area of the inappropriateness of the term Lafayette as employed in the Atlantic border region has led to the proposal by the author of the name Brandywine for the oldest of the terrace formations of that district. . . ."

This name was taken from the village of Brandywine in the best-preserved portion of the gravel plateau here described. Because of this decision, the name Brandywine will be used in this paper in the same sense that "Appomattox" and "Lafayette" were used by previous authors.

Darton and Shattuck are responsible for most of the detailed study and mapping of the Brandywine formation in Virginia and Maryland and therefore their views regarding its origin will be given in some detail, so that the reader may have before him all of the explanations that have been advanced by those familiar with the geology of the region.

Darton's interpretation of the conditions prevailing at the time the "Lafayette" gravel was being deposited is well stated in the following quotation from an early paper which deals mainly with the conditions in the region about Fredericksburg, Virginia:[6]

"From the composition and distribution of the materials it is evident that the formation was originally deposited as a continuous mantle over this portion of the Coastal Plain and extended some distance upon the seaward border of the Piedmont Plateau, and also that the materials were carried down by the rivers and lesser streams and distributed and assorted over the Coastal Plain area by the action of waves and currents."

In referring in another paper[7] to the sequence of events he describes it as follows: "Submergence; deposition of the Appomattox formation, overlapping far upon the Piedmont region." Darton's concept of the pre-"Appomattox" condition of that part of the Atlantic Coastal Plain lying in northern Virginia and southern Maryland was that of a gently southeastward sloping surface below sealevel on which the Brandywine gravel was deposited in a remarkably even sheet. As this material was

[5] The Brandywine formation of the Middle Atlantic Coastal Plain. Amer. Jour. Sci., 4th ser., vol. 40, 1915, footnote, p. 499.

[6] U. S. Geol. Survey Geol. Atlas, Fredericksburg Folio, no. 13, 1894, p. 3.

[7] Mesozoic and Cenozoic formations of eastern Virginia and Maryland. Bull. Geol. Soc. Amer., vol. 2, 1891, p. 450.

supposed to "overlap far upon the Piedmont region" to the west, the subsidence must have been considerable, probably amounting to 200 or 300 feet in the Maryland portion of the Coastal Plain. From the Piedmont upland the gravel and sand borne down by the rivers were swept out to sea for nearly 50 miles and deposited in a fairly uniform sheet, ranging from 5 to 40 feet in thickness, throughout the entire area.

Shattuck, who made a study of the Coastal Plain of Maryland soon after Darton began work on the same plain in Virginia, had a very different conception of conditions attending the development of the surface features and the formations composing them during the closing stages of the Pliocene and possibly including the earliest deposits of the Pleistocene. This he put forward in a volume entitled "Pliocene and Pleistocene" (published by the Maryland Geological Survey, 1906). His first statement, however, regarding the conditions under which these deposits were laid down, is contained in a brief article on "The Pleistocene problem of the North Atlantic Coastal Plain." [8] In this paper Shattuck makes the following statement:

> "The key to the solution of the relations existing between the surficial deposits of Maryland lies almost exclusively, according to the author, in a correct correlation of the various terraces in which they are developed throughout the Coastal Plain. In Maryland, five principal terraces are distinguished, lying one above the other, the oldest occupying the highest, and the youngest, the lowest portions of the region. Beginning with the oldest and enumerating them in succession, we have what the author has designated as the Lafayette, Sunderland, Wicomico, Talbot, and Recent. The Recent terrace is the one which the present sea is building" (page 73).

As the "Lafayette" and Sunderland are the only formations and terraces that are involved in the problem here being considered, the mode of their origin as determined by Shattuck is the only point of present interest. It seems apparent from the foregoing quotation that their author observed the clear-cut and regular appearance of the Wicomico, Talbot and Recent terraces near sealevel and then assumed that the older gravel and sand deposits must have had a similar history, and therefore that the "Lafayette" and the so-called Sunderland were horizontal or near horizontal terraces built up or planed down by the waves of the sea. The "Lafayette" terrace was placed by him on the Piedmont Plateau back of Washington, on a surface which has a present altitude of 400 feet or more and which corresponds with gravel deposits in the Potomac Valley above the Fall Line. These figures are based on present con-

[8] Johns Hopkins University Circular, vol. 20, no. 152, 1901, pp. 69-75.

ditions but it is possible that crustal movements may have changed them from their original positions. In places Shattuck incidentally mentions the possibility of deformation after the deposition of the "Lafayette" material, but even on the assumption that there has been crustal movement, his theory calls for a depth of water of at least a hundred feet on the peninsula between the Potomac and Patuxent rivers at the time of deposition.

Shattuck's recognition of the Sunderland as a formation separate and apart from the "Lafayette" was doubtless based largely on the difference in the character of the materials composing them. This is clearly shown on his map [9] of the surficial formations of this region. The "Lafayette" formation includes all that is prevailingly gravel, whereas the Sunderland is largely limited to the areas of sand previously described.

Shattuck regarded the Sunderland as representing a lower and later stand of the sea during which sea-cliffs were cut in the "Lafayette" formation and the gravel derived from this cutting was sorted by the waves and deposited on a beach at the foot of the cliffs. The following quotations from his report on the "Pliocene and Pleistocene," 1906, show clearly his concept of conditions attending the deposition of the Sunderland formation:

"This formation [Sunderland] is developed as an unmistakable terrace butting up against the Piedmont plateau or lapping around the edges of the Lafayette. The scarp line at Charlotte Hall is a part of an ancient sea-cliff of the Sunderland sea" (page 14).

"Another line of evidence is furnished by the presence of a beach gravel on the surface of the Sunderland formation as it approaches the base of the Sunderland–Lafayette scarp. The Lafayette in this region carries very little gravel and waves can not produce a shingle beach unless there is gravel at hand out of which to make it. At Charlotte Hall, however, the waves of the Sunderland sea concentrated on the beach the small amount of gravel which they secured by the erosion of the Lafayette scarp" (page 90).

This author also laid great stress on another locality as affording positive proof of the work of the Sunderland sea, as follows:

"The best localities for observing this type [that is, a wave-cut cliff modified by subsequent erosion] are to be found at Congress Heights [Anacostia] just south of the Anacostia River, in the District of Columbia. . . . At Congress Heights the surface of the Lafayette terrace lies at an elevation of about 260 feet and that of the Sunderland at about 200 feet. The descent between the two is accomplished by a cliff which is one of the most conspicuous features of the region and, in fact, of the entire Coastal Plain" (pages 69-70).

[9] Pliocene and Pleistocene of Maryland, 1906, pl. 1.

Minor Points of Difference

General statement

From the foregoing quotations it is apparent that the three geologists who have studied this region most carefully are agreed that the older gravel, which is here denominated Brandywine, was deposited in the sea, either in the form of deltas or as widespread sheets, and that the highest stand of this sea was on land which now has an altitude ranging from 300 to 500 feet, and also that its margin is marked by well-developed beach deposits. One geologist also maintains that there is evidence of a sea-margin at altitudes ranging from 166 to 200 feet. As these conclusions differ from those reached by the present writer, the first subject to be considered is the evidence for and against the marine origin of the deposits of Brandywine gravel.

Three kinds of evidence have been put forward in support of the idea that the gravel was deposited in or on the shore of the sea: these are (1) the presence of gravel deltas at the Fall Line which is supposed to mark the former location of the mouths of the various streams flowing into the sea, from Delaware River on the north to James River on the south; (2) the existence of well-marked sea beaches, especially on or adjacent to the Fall Line; and (3) the presence of wave-built terraces at many places within the area here considered and in the adjacent area to the north.

Gravel deltas

The writer has made a more or less detailed study of the Fall Line from Trenton on the north to Richmond on the south, and he has found no indications of delta deposits on the Piedmont Plateau or the adjacent Coastal Plain. If such deposits were made, their presence today could easily be determined by an examination of the gravel within a few miles of the Fall Line, to see if it has the characteristic form and structure of a delta deposit. If the water near the shore were deep, the building of the deposit at every flood would take place by the addition of a foreset bed on top of the bed laid down when the last flood affected the river, and thus there would be foreset bed upon foreset bed, or cross-bedding, as it is usually termed. If the water near the shore were shallow, but increasing in depth seaward, the first deposit of gravel and sand by the inflowing stream might not produce appreciable foreset beds, but as soon as the delta was built out into deeper water, the characteristic foreset structure would be developed. The variation in the depth of a deposit of sand and gravel off the mouth of a river may also be used as evidence

of the conditions under which the deposit was made. Since the top of a delta coincides closely with the surface of the water body in which it is formed; and since the bottom, whether it be of the sea or of a lake, slopes in general away from the shore, the delta should increase in height—unless it has been affected by subsequent erosion—from the old mouth of the stream seaward. If it were built out many miles into the sea or any other body of water, its height would necessarily be considerable and when elevated above sealevel it would become a prominent object in the landscape and one that could be easily detected.

The writer is familiar with all of the more extensive deposits of gravel at or near the Fall Line between Trenton and Richmond and he has not in any case found a suggestion of delta structure, either in the form of foreset beds or in increasing height seaward. Wherever structure is apparent in the gravel it is rudely horizontal, but with considerable irregularities which would suggest at once deposition on land rather than in the sea. The thickness of the deposits examined is in all cases greatest near the Fall Line, growing progressively thinner in the direction of the sea. The one at the mouth of the Potomac is thickest (40 feet) near the Fall Line and gradually decreases in thickness for a distance of 65 miles. The conclusion is, therefore, that until foreset-bedding can be shown in the gravel deposits on the Coastal Plain adjacent to the Fall Line, or increased thickness pointed out in similar deposits as they recede from this line, the delta hypothesis lacks the support of an imporant, perhaps an essential, type of evidence in its behalf.

ABANDONED BEACHES

The second line of evidence to be considered is the presence or absence of old beaches on or adjacent to the Fall Line. This, it must be admitted, is a much more obscure problem than the determination of delta deposits, and it should be approached with due caution and an open mind. The special work upon which the writer was engaged was an attempt to trace gravel deposits along the larger streams, and, in so doing, his starting point was in almost all cases the Fall Line, where such deposits are much more numerous than they are farther up the streams. At the points where each of the larger streams, with the possible exception of Delaware River, issues from the Piedmont upland, there is an abundance of gravel which doubtless has led to the assumption that it must mark the former position of the shore of the sea. There are, however, several facts regarding the character and distribution of the gravel that should be considered before any conclusion is reached.

The first fact is that the greatest deposits of gravel occur near the places where the large streams cross the Fall Line and smaller deposits in similar situations on some of the minor streams, but in the intermediate areas having the same altitude and relation to the Fall Line, deposits of gravel are entirely wanting.

This would not have been the case if the large deposits of surficial material marked the position of the shore, because some of this material would have been swept along shore by the waves and currents. These agents might not have been strong enough to transport cobbles or even pebbles, but they certainly would have been able to carry an appreciable amount of sand which without much doubt originally accompanied the gravel. The writer has looked in vain for deposits of sand or gravel extending laterally from the principal accumulation near the river.

Another significant feature is that the gravel deposited by Potomac and Susquehanna rivers is different in appearance and composition from that deposited by smaller streams, such as Patuxent, Patapsco and Gunpowder rivers. That deposited by the larger streams contains well rounded pebbles of quartz, quartzite and chert from the Paleozoic rocks, whereas that deposited by the smaller streams is prevailingly quartz which is in part rounded, the other part being either angular or subangular. The difference in appearance of the two gravels is due to the fact that the material carried by the smaller streams is largely of local origin, being derived from the schist over which the streams flow near the Fall Line, whereas that carried by the larger streams comes from a distance and has been subjected to more intensive abrasion in transit. If both kinds of material were delivered to a beach the waves would probably reduce them to a rounded condition and it would be impossible to distinguish the local material from that which came from a distance except by its different composition. The conclusion is that this line of evidence is in favor of local deposition on a land surface and not in the sea or on a beach which the waves had formed.

The next point to be considered is whether or not sporadic deposits of gravel on the Fall Line are necessarily indicative of shore conditions. In tracing deposits of gravel from the interior down to the Fall Line, the writer found, in almost all instances, that on approaching that line the relief of the surface upon which the gravel was deposited grows less and less pronounced, until at the line itself the upland surface, although more or less dissected by the recent work of the streams, is strikingly like a peneplain. Wherever streams emerge upon such a surface, their velocities are reduced and they tend to meander more and more broadly and

to drop the load of sand and gravel which, before they entered the peneplain, was carried with ease. In this manner deposits of gravel a few rods or miles in extent were laid down regardless of the position of the sea, but in every instance there would be a definite limit to such action beyond which no gravel was carried by the streams. This condition was found to be so common in northern Virginia, Maryland and Pennsylvania that the writer is convinced that the extensive flats on the Fall Line are not due to wave action, but to peneplanation, and that in all probability the Fall Line in this region has been more or less stationary, affording a hinge upon which the great uplifts of the interior moved. In conclusion, all of the evidence in the writer's possession regarding the gravel deposits on or near the Fall Line seems to indicate that they are entirely subaerial deposits and that in no case have they any direct relation to the sea.

WAVE-CUT OR BUILT TERRACES

Wave-cut or built terraces must originally have had more or less continuity, and one is hardly justified in using a terrace as evidence of marine conditions unless he finds it to be of considerable length or its parts arranged in such a manner as to suggest their former continuity. The region about Washington has been cited by several authors as affording examples of both marine beaches and wave-cut terraces, but every feature cited in proof of this hypothesis consists of a single example of very limited extent. The writer, in his study of gravel deposits and terraces in and about the District of Columbia, has failed to find a single instance in which the supposed beach or terrace is continuous for any great distance, and in all cases similar features at higher or lower levels are equally well developed. This leaves no ground for the selection of a particular terrace as the only one representing the work of the sea.

Sunderland Formation

GENERAL STATEMENT

In addition to the above-mentioned features occurring on or near the Fall Line, the Sunderland formation of Maryland has been described by its author as affording positive proof that, at the time of its deposition, the southeastern part of the State, or the peninsula lying between Potomac and Patuxent rivers at altitudes ranging from 167 to 200 feet, was under the waters of the Atlantic.[10]

[10] Shattuck's statements regarding the present height of the marine waters of that time are conflicting and indicate that he either changed his mind or was careless in the use of figures. In "The Pleistocene problem of the North Atlantic Coastal Plain" (Johns Hopkins Univ. Circ., vol. 20, no. 152, 1901, p. 74), he makes the following statement:

CONDITIONS AT CHARLOTTE HALL

The critical locality of this formation, as described by its author, is Charlotte Hall, a small village on the Washington–Leonardtown highway, about 35 miles from Washington. The situation in and about this place is shown in figure 2 which is a reproduction of the topographic map of the area. The statement has been made that the 20-foot scarp at the north edge of the village is a sea-cut cliff that was formed when the Sunderland sea covered the site of the village to a depth of 3 or 4 feet, and gravel that was found near the foot of this scarp and in the streets of the village was supposed to have been derived from the uppermost or Brandywine material when the waves washed the foot of the cliff. On this evidence the material forming the plain underlying the village was supposed to be of Sunderland age and of marine origin and, therefore, a formation distinct from the "Lafayette" (Brandywine) formation. If this interpretation were accepted, it would follow that practically all of the gravel lying south of Charlotte Hall was deposited in the sea, which was relatively 170 feet higher than tidewater today, and consequently that this gravel constitutes a formation distinctly younger than the gravel to the north of the village.

On careful examination, the writer found that the flat upon which Charlotte Hall is built, at an altitude of 167 feet, is underlain by a bed of gravel about 6 feet in thickness, with a layer of quite large cobbles at its base. It is from this gravel that the spring, for which the village is famous, issues. In times past the gravel bed was probably not well exposed except in the grassy slope leading from the highway down to the spring, and hence it is not surprising that gravel found in the streets and at the base of the scarp was ascribed, not to weathering of the underlying mass, but to the erosion of the overlying material composing the scarp.

The object of the present investigation was to determine whether the bed of gravel mentioned above is restricted to the immediate vicinity of

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"In southern Maryland the base of the Sunderland terrace lies at about 90 feet, but rises gradually toward the northwest, until at Charlotte Hall the surface of the bench is found at 170 feet."

In the Patuxent folio (U. S. Geol. Survey Folio No. 152, 1907, p. 2) by Shattuck, Miller and Bibbins, the altitude of the Sunderland is given as follows:

"The surface of this [Sunderland] plain reaches an altitude of about 180 feet at Charlotte Hall, just beyond the southern margin of the quadrangle, and of 200 feet near Anacostia."

The bench at Charlotte Hall has a height, according to the topographic map, of 167 feet, and this represents the supposed marine beach. If the Sunderland plain is put at 180 feet it will be near the top of the sandy scarp which was regarded by Shattuck as a sea-cut cliff.

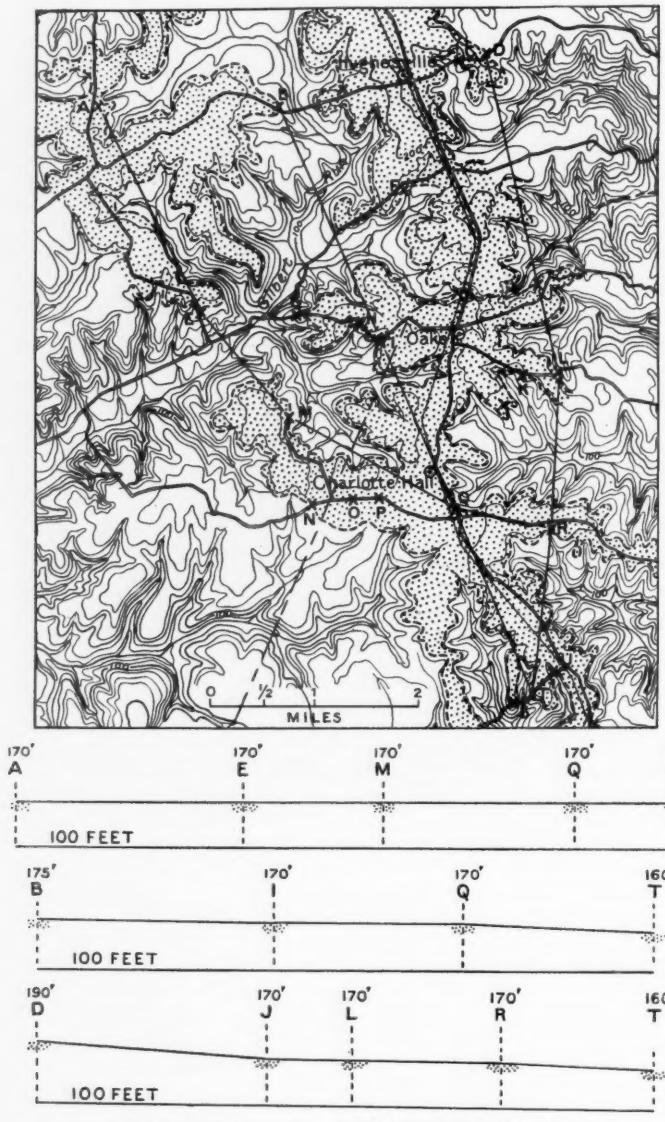

FIGURE 2.—*Contour Map of Charlotte Hall and Vicinity*

Showing localities at which gravel was found, altitude of the deposits and areas probably underlain by the bed; also sections showing the comparative altitudes of the more prominent exposures.

the village and to the region to the south, as described in the Maryland report, or is the same as that underlying the region to the north. If it is limited to Charlotte Hall and the region to the south, then the Sunderland formation must be recognized as distinct from the Brandywine ("Lafayette") formation, which has been regarded by all geologists who have worked in this region as forming the surface of the plateau north of Charlotte Hall.

In order to solve this problem, the writer examined the region surrounding Charlotte Hall with considerable care for the purpose of determining the position and altitude of any gravel bed that might be exposed. As a result of this work, 17 exposures were found within a radius of 3 miles, on a bed of gravel, ranging in thickness from 2 or 3 feet in some of the easternmost exposures, to 8 feet or more in those lying farther west. As far as could be determined, all of these exposures are practically at the same altitude, differing not more than 10 feet at any one locality. The localities at which gravel was observed are indicated by letters on figure 2, as follows: *Q* is a gravel pit a short distance south of the spring at Charlotte Hall; *R* is also a pit showing at least 7 feet of gravel, of the same texture and fineness as the gravel at *Q*; *U* is a surface outcrop in a small ravine which shows an abundance of gravel; *S* and *T* are roadside cuts at the same altitude, showing a bed of gravel about 6 feet in thickness; *P* is merely a showing of gravel on the surface of the flat plain west of Charlotte Hall; *O* is a similar showing by the roadside and also an exposure in a shallow pit; *N* is presumably the westernmost outcrop of this gravel bed on the plateau east of Gilbert Run. The gravel here is thin and is exposed where the road makes a slight descent in a westerly direction; *M* is a flat covered with an abundance of gravel and the surface here evidently marks the top of a fairly thick bed; *E* is a roadside cut through the bed of gravel, showing a thickness of 4 feet 6 inches; *G* is a similar exposure of undetermined thickness on the road west of Oaks and at the top of the bluff bounding the valley of Gilbert Run. *H* and *I* are hillside exposures in which the gravel is so abundant that probably it would call for a bed at least 6 feet in thickness to supply the material; *J* is also a hillside exposure of several thin beds which are supposed to be the representatives of the thick bed west of the main highway; *K* is a roadside cut showing only a small amount of very fine gravel, and a similar exposure was seen at *L* on the opposite side of the ridge. The last three exposures are interpreted as representing the transition from gravel to sand in an easterly direction. *F* is a hillside exposure in a field where the gravel is so abundant and so coarse that it probably

represents a bed more than 6 feet in thickness. *A* is a shallow pit in a bed of gravel where not more than 4 feet of that material is exposed. This probably represents the westward thinning from the axial line of the old stream which seems to correspond approximately with section *B–T*. *B* is a large pit where the gravel is prevailingly fine, except a layer near the base in which there are boulders up to 12 inches in diameter. *C* and *D* are exposures in road cuts and in old pits where the gravel is generally fine and the bed not more than 3 feet in thickness.

Another line of evidence regarding the identity of the gravel seen at the various exposures is that afforded by the character of the materials constituting the bed. The most striking feature is the coarseness of the material composing the basal layer. This is well shown at the spring at Charlotte Hall where the cobbles forming this layer—some of which are as much as 12 inches in diameter—have been gathered together around the various outlets of the water. The same feature was observed at fully nine-tenths of the localities listed above, showing conclusively that this is not a feature restricted to the so-called Sunderland formation, but occurs in other localities where the gravel has been generally recognized as belonging to the "Lafayette" formation.

In order that the reader may visualize more clearly the regularity of this bed of gravel, three cross-sections have been introduced in figure 2. Section *A–R* connects the exposures shown at *A, E, M, Q* and *R;* section *B–T* connects exposures *B, I, Q* and *T;* section *D–T* connects exposures *D, J, L, R* and *T*. The remarkable feature of the sections is that in no case does a determined point differ from other points on the same cross-section more than 10 feet, except in section *D–T*, where there is a difference of 20 feet, but this lies entirely north of the area in question and has no bearing on the problem. The obvious conclusion from this evidence, coupled with the similarity in the structure of the bed, as outlined above, is that the gravel bed underlying Charlotte Hall, which Shattuck maintained to be of Sunderland age, is identical with the gravel at other localities just described, and since the gravel bed north of Charlotte Hall is regarded by all geologists who have examined the region as "Lafayette" (Brandywine), the bed underlying Charlotte Hall must be considered as being of the same age.

The conclusions of previous workers regarding the existence of the Sunderland as a formation of marine origin and separate and distinct from the "Lafayette" (Brandywine) formation was based largely upon the assumed presence of a sea-cut cliff at Charlotte Hall. The basis for this conclusion is (1) the presence at this place of a rather deep, flat-bot-

tomed trench across the main divide between the Potomac and Patuxent rivers, and (2) the 20-foot scarp which borders this trench at the north edge of the village.

The writer has examined this trench quite carefully, but found no evidence that it is of marine origin or was cut by a stream of water and then occupied by the sea. There are at least three such trenches across this drainage divide—one, as stated above, at Charlotte Hall, and two about 5 miles south of Upper Marlboro. Each of these trenches is due to the headward erosion of streams whose sources are on opposite sides of the divide and which are so situated that they found little material other than sand to be eroded at their heads. Because of the absence of gravel or other resistant material at the surface, the valleys are relatively wide and the trenches across the drainage divide range from one-quarter to one-half mile or more in width. These are generally flat-bottomed, because erosion has progressed until a more resistant stratum of gravel was encountered and this material has resisted the downward cutting but has permitted the widening of the trench. This is particularly the case at Charlotte Hall, where the bed of gravel, previously described, has retarded down cutting but not lateral erosion, and consequently the result is a distinct flat on which the village is built.

The writer was not able to find any evidence in these trenches of their occupation by the waters of the sea. If the one at Charlotte Hall is the result of wave work, then it is reasonable to conclude that the other trenches may have been formed under similar conditions, but such a comparison has never been made, probably because their altitudes are different—that at Charlotte Hall being 167 feet and the two south of Upper Marlboro about 200 feet.

Since the trenches of themselves give no indication of having been formed by wave action, then the validity of the Sunderland formation rests entirely on whether or not the 20-foot scarp at the north edge of Charlotte Hall is of marine origin.

The situation regarding this scarp is as follows: The village is located on the divide between the two major drainage basins of this region and this divide is here absolutely flat and the flat extends some 2 miles to the west. As previously stated, the writer has proved conclusively that this flat is underlain and held up by a bed of gravel of Brandywine ("Lafayette") age about 6 feet in thickness. The scarp in question, which is about 20 feet in height, is composed of sand and loam that rest directly upon the Brandywine gravel. Shattuck's idea was that the pebbles and cobbles which occur at the base of this scarp were derived

from the overlying sand and then segregated by waves at its base. Since the formation in which the scarp is cut is composed almost entirely of sand, it is difficult to understand how its erosion by either streams or waves could produce pebbles and cobbles up to 8 or 10 inches in diameter. The gravel at the foot of the scarp is no more abundant than it is over the entire area occupied by the village and the plain to the west. Because of this fact no evidence of wave action is apparent, but on the contrary, the gravel in the village as well as that at the foot of the scarp has all of the characteristics of having resulted from the weathering of the gravel bed on which the village is built. All of the surface features in the vicinity of Charlotte Hall and the materials of which they are composed indicate that the latter is a part of the Brandywine ("Lafayette") formation and that the configuration of the surface here is the natural result of stream erosion and the weathering of a formation composed of alternating beds of sand and gravel, rather than the result of wave work in a narrow and shallow inlet of the sea.

CHARACTER OF STREAM VALLEYS

Another argument advanced by Shattuck for the differentiation of the Sunderland from the "Lafayette" (Brandywine) is the difference in character of the valleys which the streams have cut in the two formations. His statement[11] is as follows:

> "An even more significant feature of the topography in the vicinity of Charlotte Hall is furnished by two generations of stream valleys. One of these, the older, is now dry and unoccupied. It penetrates the Lafayette formation and formerly drained from it into the Sunderland sea. The other generation of valleys is now being rapidly extended inland from the Patuxent and Potomac rivers. These latter valleys are steep-sided and V-shaped and at the present time have worked their way so far back on the divide as to drain the edge of the Sunderland formation in the vicinity of Charlotte Hall. These two valley systems are not only distinct in age, but they have no physical connection whatsoever."

The present writer does not question the facts stated above, but he is far from satisfied that Shattuck's explanation is correct. In the region about Charlotte Hall there is a marked difference in the character of the valleys of the minor streams that are cut in the bed of gravel and those cut in the overlying sand, which in places is as much as 20 feet in thickness. According to Shattuck, the shallow and indefinite character of the latter is an indication of a much greater age and consequently the gravel and the overlying sand must belong to different formations; but

[11] Pliocene and Pleistocene. Maryland Geol. Survey, p. 90.

these facts are also susceptible of a very different explanation. The big spring at the base of the gravel bed at Charlotte Hall is convincing proof that this bed is the most important water carrier in this region, and doubtless most of the water derived from rain and snow falling on the upland surface quickly sinks through the porous sand into the underlying gravel, and a very small percentage finds its way by surface drainage lines into the principal streams of the region. Because of this condition it is not reasonable to expect that small ravines in the sand, overlying the bed of gravel, would be deeply cut or would ramify and completely cover the region. On the other hand, the drainage which originates in or on the gravel—a much more resistant stratum and one resting on Tertiary formations—would almost all find its way to the surface and be carried away by surface streams. Thus the streams originating in the gravel would have a more vigorous flow and their channels would be sharper and deeper than those in the overlying sand. Because of these radically different conditions the dissimilarity in the character of the drainage channels is in no wise an indication of difference in age and should not be relied upon to separate the geologic formations.

CONDITIONS AT ANACOSTIA

Before a final decision is reached on this question it will be well to consider another locality which Shattuck regarded as furnishing indisputable evidence of the presence of the sea at the time of deposition of the Sunderland formation. This is at Congress Heights or Anacostia on the east side of Potomac River at Washington. His description of this locality is given on page 834. At the Anacostia locality there is a well-developed gravel-covered terrace at an altitude of 200 feet which was considered by him to be of marine origin and definitely assigned to the Sunderland formation. No one visiting this terrace would for a moment question its existence, but there might arise a very decided difference of opinion regarding its interpretation. If gravel-covered terraces are always indicative of the marine conditions there could be no room for difference of opinion regarding its origin, but no geomorphologist would for a moment agree to such a proposition. A gravel-covered terrace may be produced either by streams or by waves, and therefore it is necessary, before arriving at a decision regarding its value, to consider the evidence for and against each of these possible modes of origin.

On the east side of Potomac River from Washington south, to a short distance beyond Alexandria, there are several gravel-covered terraces ranging in altitude from 150 to 260 feet, and on the west or Virginia side there are terraces having even a greater range in altitude. If one

of these terraces is of marine origin, we should expect to find it fairly continuous down the valley on either the east or the west side. If, on the other hand, the gravel-covered terrace is merely a fragment of an old river floodplain which was deposited at the base of a cliff undercut by the stream and abandoned when the river found a new course, it is probable that no other remnant would be found at the same altitude, because such a stream would be rejuvenated with each uplift of the land or with increase in precipitation, and would form a new terrace at a different level. The test to be applied to the case under consideration, therefore, is whether or not the terrace remnants are at the same altitude or have a common and presumably very slight downstream slope, or whether they are so irregular in altitude and occurrence that no consistent grouping can be determined.

The present writer has not been able to trace any particular terrace for a distance greater than two or three miles, and rarely can two terraces be found either at the same altitude or arranged in such a manner as to indicate that they were formed on a slight downstream slope. One of the best-developed terraces in this portion of the Potomac Valley is that upon which the town of Clarendon, Virginia, is built, at an altitude of 250 feet. The next in altitude is at Anacostia, on the east side of the river, at an altitude of 200 feet, but this extends southward only as far as the latitude of Alexandria and is not known below that place. A third terrace at 150 feet is well shown on the Virginia side of the river on the ridge lying north and east of Fourmile Run and also on the hills west of Alexandria.

The writer has carefully considered the evidence afforded by gravel-covered terraces in this region and he is forced to the conclusion that they are not indicative of marine conditions but, on the other hand, are all more satisfactorily explained as the results of erosion and deposition by streams flowing on the surface of the land.

Offshore Transportation of Gravel

There can be no question about the competence of waves and along shore currents to transport sand and even much coarser material, not only along the shore, but also seaward from the shore for a short but undetermined distance. The distribution of the gravel shown in figure 1 might, at first sight, seem to be easily explainable on the hypothesis that it was carried southward along the shore by such currents, but when it is understood that such an accumulation of gravel is limited to the Potomac drainage and does not show on the Susquehanna or James rivers or on

smaller streams lying between these major rivers, this hypothesis seems to lose much of its value. The writer can not conceive of any condition on this supposed coastline that would prevent the transportation along shore of gravel and sand from the mouth of the Susquehanna—the largest river in the district—and at the same time would carry such materials from the mouth of the Potomac and distribute them over an area of about 1,500 square miles which, according to the generally accepted hypothesis, was covered with sea-water to depths ranging from 100 to 400 feet.

It is equally futile to appeal to oceanic currents to explain this distribution, for the water was too shallow for the action of the strongest currents, such as the Gulf Stream that carefully avoids the Continental Shelf, which at its margin is 600 feet below tide level. The only oceanic stream that could be appealed to is the Labrador current, which in this latitude is crowded in-shore by the Gulf Stream and becomes so weak that it could not possibly transport material of this character.

Sea-margin in Brandywine Time

As the facts so far considered tend to show that the Brandywine gravel was deposited on the land as an alluvial fan, it is appropriate now to consider the position of the margin of the sea and whether or not it has left a record which may be read by those familiar with such features. The writer has searched the Fall Line from Philadelphia southward to Richmond with the expectation that at some point evidence of the existence of a former beach line would be revealed, but no such evidence has been found; he has also studied carefully that part of the Coastal Plain lying in southern Maryland and, to a limited extent, the same feature in northern Virginia, with the same result. Finally, a map study of the Coastal Plain of eastern Virginia revealed the long-looked-for beach at an altitude of 90 to 100 feet above present sealevel. The results of this map study have been confirmed by an examination in the field, carried on by Chester K. Wentworth, who examined this old beach from near the present mouth of Potomac River to the North Carolina line in the vicinity of Branchville. The results of this work, including a map of the beach, have recently been published by the Virginia Geological Survey.[12] Wentworth calls it merely the "Sunderland terrace," but since he is not familiar with the Sunderland at the type locality, his use of the name has little weight. He found no evidence of marine conditions above this old beach and in that respect his conclusions are in agreement with those of the present writer.

[12] Sand and gravel resources of the Coastal Plain of Virginia. Bull. 32, 1930, pp. 1–146.

Since this beach is well developed near the town of Surry, in Surry County, just south of James River, it will be referred to as the Surry beach. South of James River the Surry beach, as shown on the contour maps, separates a rather irregular upland surface on the northwest from a very flat lower land, at an altitude of about 90 feet, on the southeast. Old sand spits are plainly visible on this beach which can generally be distinguished as a low ridge on an almost featureless plain. North of James River the beach is not so well marked, but, as shown in figure 1, it can be traced by the limit of the 100-foot contour line almost directly to the mouth of Potomac River. The lack of a distinct scarp in this area is probably due to the flatness of the land on both sides of the beach, but especially to the land on the northwest, which must have been almost if not quite a salt marsh.

The Surry beach undoubtedly marked the margin of the sea at the time of deposition of the alluvial fan of Potomac River, and that stream reached tidewater somewhere near the eastern bend of Rappahannock River a short distance above its mouth. Elevations on the alluvial fan show that the surface was near sealevel at Leonardtown, Maryland, and consequently the descent of the stream from that point to its mouth must have been so slight as to be negligible. The Surry beach is the highest one that the writer has been able to find in this part of the Coastal Plain and he regards it as contemporaneous with the deposition of the Brandywine gravel and the building of the alluvial fan of Potomac River.

Formation of an alluvial Fan

If the writer is correct in his conclusion that the Brandywine gravel of the Coastal Plain of southern Maryland and northern Virginia is a terrestrial deposit, then the next step is to consider what conditions prevailed in that and adjacent areas that would result in a deposit of this character on the surface of the land distinctly above tide-level. A stream, in passing from a region of high relief on relatively hard rocks to one of low relief, will deposit its load of sand and gravel in the form of a fan, in places miles in width and scores of miles in length, and the gravel, owing to the frequent lateral shifts of the river, may be fairly evenly distributed over its surface, but in general is thickest at the apex, where the stream emerges from the upland and trails off down the slope in various directions for an indefinite distance.

To the earlier workers the sea, only a few miles away, seemed to be so competent to handle and transport rock material that it was naturally regarded as the all-important factor in shaping the land forms of the

Coastal Plain. At the present time it is impossible to say who conceived the idea that the deposit of gravel opposite Washington represents an old alluvial fan, but the writer is inclined to believe that Laurence La Forge was the first to suggest such an explanation. Since that time both La Forge and the writer have been gradually accumulating evidence on the subject until, at the present time, the available data seem to afford conclusive proof of the accuracy of La Forge's hypothesis.

Age of Fan indicated by River Gravel

The present interpretation of the gravel deposits of southern Maryland as an alluvial fan built by Potomac River has added one more link in the chain of evidence now available for deciphering the late geomorphic history of the Piedmont region and for correlating it with the depositional history of the Coastal Plain, and it is hoped that similar work will be carried on along the Fall Line in both directions in order that a more detailed and rational interpretation of the surface features and materials of these two provinces may be made.

Up to the present time the writer has been able to trace the remnants of two beds of gravel marking old floodplains of Potomac River from the Fall Line northwestward to beyond the Shenandoah Valley.[13] The uppermost of these two gravels has been called in recent reports Bryn Mawr, and the lowermost one Brandywine; but it now seems doubtful if either of these names is appropriate, and until this question is settled the writer prefers to call the upper and older one Gravel A, and the lower and younger one Gravel B. These gravel beds mark two cycles of erosion which were interrupted by elevation shortly after the major streams had reached maturity and before they had widened their valleys in the hard rocks to any great extent.

These are the highest and oldest gravel beds found in the Potomac drainage basin, but in ascending the river Gravel A is found to have a definite position about 150 feet below an extended flat which was recognized by George W. Stose[14] as the Harrisburg peneplain. The present writer agrees with Stose in this correlation and also in his identification[15] of the same peneplain in a shale upland just back of Chambersburg, Pennsylvania, at an altitude of 750 feet. Gravels A and B were traced by the writer up Conococheague Creek into Pennsylvania, and the town of Chambersburg is built largely upon a terrace of Gravel A at an altitude

[13] Late geologic deformation of the Appalachian Piedmont as determined by river gravels. Proc. Nat. Acad. Sci., vol. 15, no. 2, 1929, pp. 156–161.

[14] The Pawpaw–Hancock folio. U. S. Geol. Survey, no. 179, 1912.

[15] The Mercersburg–Chambersburg folio. U. S. Geol. Survey, no. 170, 1909.

FIGURE 3.—*Longitudinal Section along Potomac River above Washington*

The section follows the main deposit of the alluvial fan from Washington to Ridge, Maryland. It illustrates the writer's idea that Gravel A, although deformed above Washington, probably passes under the fan or is merged with its lowermost beds. Gravel B apparently crosses Gravel A and then is known to form a thin veneer on the top of the fan for a distance of only a few miles. On this interpretation, Gravel A is older than the fan and Gravel B is younger than its main body.

of 600 feet. These facts indicate that Gravel A, which is here 150 feet below the peneplain just referred to, represents the next partial cycle of erosion subsequent to that which resulted in the formation of the Harrisburg peneplain, and that Gravel B, the second below the Harrisburg, is the latest feature of this kind that has left any record on the hard rocks of this region.

In the Shenandoah Valley, Gravels A and B are about 100 feet apart, but on approaching the Fall Line this interval, as shown on the section in figure 3, changes considerably. From the Shenandoah Valley to near the Great Falls of the Potomac, Gravel A descends with remarkable regularity, but at the latter point it rises suddenly from an altitude of about 400 to 520 feet and then descends toward the Fall Line, reaching its lowest known point in this section in Washington at an altitude of 400 feet. Gravel B descends continuously from an altitude of 400 feet in the Shenandoah Valley to 300 feet at Great Falls, and then rises to about 360 feet at the west line of the District of Columbia. From this point it descends to 310 feet at the Soldiers Home and 300 feet at the summit of Good Hope Hill. In Washington and on Good Hope Hill this gravel may be recognized by a peculiar band of yellowish-brown sand and by the moderate weathering of the quartz pebbles. Beyond Good Hope Hill

Gravel B appears to spread out as a thin veneer on top of the bedded deposit constituting the body of the alluvial fan. Because of this relationship the alluvial fan is regarded as being older than Gravel B.

As the alluvial fan of the Potomac appears to be older than Gravel B, is it reasonable to conclude that it is of the same age as Gravel A, or does it correspond with the interval between these two gravel beds? The writer has already considered in another paper the deposition of gravel on a floodplain,[16] so all that is necessary here is to say that river gravel is preserved on a floodplain only in the late mature or postmature stage of river development. The deposition of gravel on an alluvial fan is a very different matter and occurs in an earlier part of the cycle. As an alluvial fan is built where an active river emerges from its confining walls in a rough or mountainous region and enters a plain with a relatively low gradient, much of the material carried by the stream will be dropped at the point where the gradient changes and the confining conditions cease to exist. Because of these facts alluvial cones are built only by very active young, or adolescent streams, or streams in the early stage of maturity, because at those times the streams are carrying a great amount of coarse material and as soon as they reach the open plain this load is dropped in the form of a fan. Because gravel deposition on the floodplain of a stream and gravel deposition on an alluvial fan can not be carried on extensively at the same time, the deposits can not be of the same geologic age and permanent deposition by a stream on its fan will always precede deposition on its floodplain.

In view of this explanation, the gravel composing the alluvial fan of the Potomac was laid down immediately preceding the deposition of Gravel B, and therefore is only slightly older than that bed.

Conclusions

The conclusions of the present writer may be summed up as follows: The surface materials on the Coastal Plain of southern Maryland and northern Virginia were deposited on a plain sloping very gently south or southeast toward the sea, the margin of which was the Surry beach in Virginia, whose present altitude is 90 to 100 feet; the Sunderland formation at Charlotte Hall, Maryland, the real type locality, can not be differentiated from the adjacent Brandywine gravel and therefore should not be regarded as a separate formation; the terrace heretofore recognized as Sunderland, in a type locality near Washington, is merely a river ter-

[16] The geomorphic value of river gravel. Bull. Geol. Soc. Amer., vol. 40, 1929, pp. 515–523.

race which was formed above sealevel, and consequently this name should not be applied to marine terraces in other parts of the Coastal Plain; the Brandywine gravel is a true alluvial fan composed of sand and gravel brought down by Potomac River in the epoch of rapid downcutting following the deposition of Gravel A and preceding that of Gravel B and therefore is not contemporaneous with either of the two high-level gravels found on Potomac River, Susquehanna River or the Fall Line.

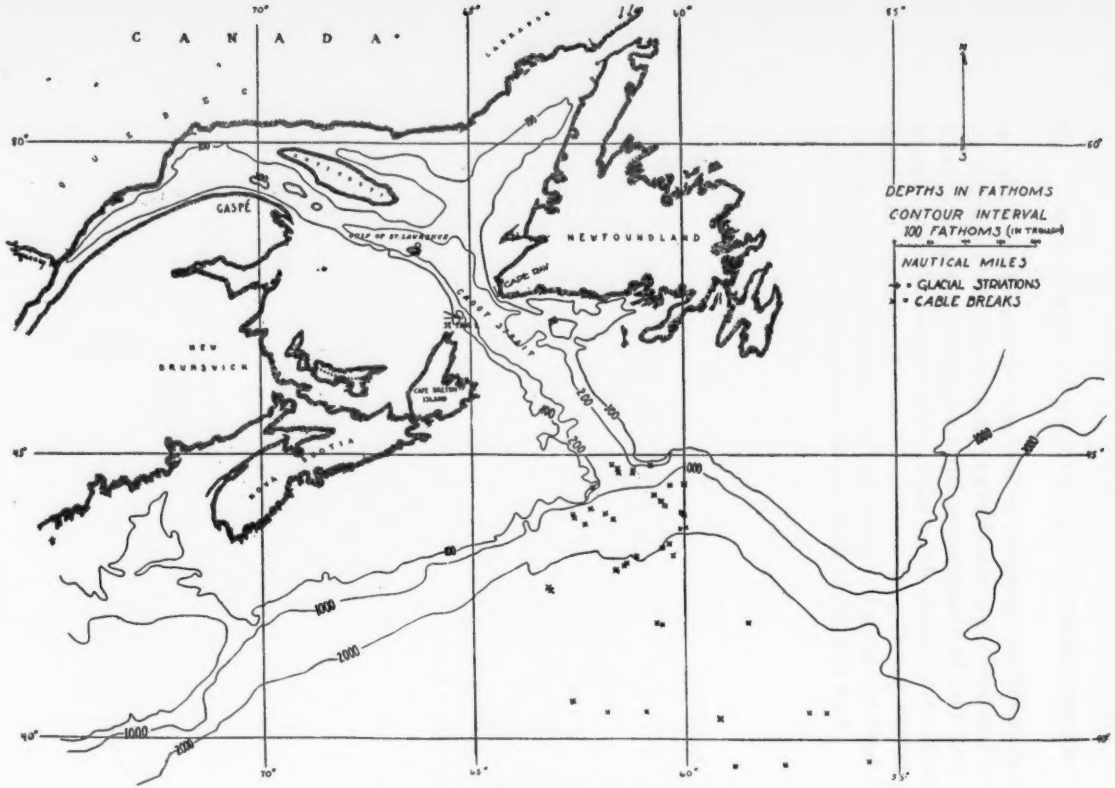

FIGURE 1.—*Saint Lawrence submarine Trough*

Source, U. S. Hydrographic Office Chart No. 1412.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 42, PP. 853-864, 9 FIGS. DECEMBER 31, 1931

SAINT LAWRENCE (CABOT STRAIT) SUBMARINE TROUGH[1]

BY FRANCIS P. SHEPARD

(*Read before the Geological Society December 31, 1930*)

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INTRODUCTION

The Saint Lawrence estuary or submarine valley extends inland to the vicinity of the city of Quebec. In its upper portion it is fairly shallow, but from a point near the mouth of the Saguenay out to the edge of the continental shelf, 750 miles away, there is a submarine trough, most of which is between 100 and 300 fathoms deep (Figure 1). One large tributary of the trough extends up towards the Strait of Belle Isle and has a branch on the north side of Anticosti Island.

The Grand Banks earthquake of November 19, 1929, which produced 63 breaks in the transatlantic cables, had its epicenter just outside the Saint Lawrence trough. Studies of this earthquake have led Prof. J. W. Gregory, Dr. Arthur Keith, and Dr. E. A. Hodgson to conclude that the

[1] Manuscript received by the Secretary of the Society March 13, 1931.

trough is a fault graben.[2] Previously it had been considered by others to have been due to river erosion followed by drowning.[3]

Basis of Present Report

The present consideration of this trough is based on a complete study of the various charts of the region, combined with a special investigation of Cabot Strait and a brief visit to the north coast of Gaspé. The Cabot Strait trip, made in the yacht Dorello, included the taking of soundings as well as the study of the coast on both sides of the strait and of St. Paul Island within the strait.

Glacial Erosion

The conclusion which resulted from this study was that the Saint Lawrence trough probably was started by river erosion, possibly in part along fault lines. Later, during the glacial period, tongues of ice moved down the valley, causing great deepening and widening. The present form of the trough is believed to be due principally to this glaciation, making it a submarine glacial trough.

Evidence of Glaciation

Since the glacial hypothesis has not been presented previously, it seems advisable to examine the evidence for the movement of glaciers down this trough. It is generally believed that the interior of the Gaspé Peninsula was not covered by the Wisconsin ice sheet and possibly not by earlier ice sheets from the Labrador center.[4] Since it is equally certain that the White Mountains and Mount Katahdin in Maine, despite greater elevation, were covered by the Wisconsin glaciers at a greater distance from the center,[5] we are confronted with the difficulty of explaining what happened to the ice which came across Quebec towards Gaspé. It looks as if this ice was deflected down a pre-existent Saint Lawrence valley. Coleman termed this ice mass the "Saint Lawrence lobe."[6] To keep this ice from flooding over the Gaspé highlands, considerable velocity of ice move-

[2] J. W. Gregory: The earthquake south of Newfoundland and submarine valleys. Nature, vol. 124, 1929, p. 945.
Arthur Keith: The Grand Banks earthquake. Supp. Proc. Eastern Section Seis. Soc., 1930.
E. A. Hodgson: The Grand Banks earthquake. Presented before the Eastern Section Seis. Soc., 1930.
[3] J. W. Spencer: Bull. Geol. Soc. Amer., vol. 14, 1903, p. 211.
[4] A. P. Coleman: Geol. Survey Canada, Bull. 34, p. 12 and fig. 1.
[5] C. H. Hitchcock: Proc. Amer. Assoc. Ad. Sci., vol. 24, 1876, pp. 92-96.
J. W. Goldthwait: Amer. Jour. Sci., 4th. ser., vol. 35, 1913, p. 3.
[6] A. P. Coleman: Op. cit., fig. 1.

ment down the Saint Lawrence valley (now the Gulf of Saint Lawrence) must have been maintained. Glacial striæ in northwestern Newfoundland and adjacent Labrador point to the southwest[7] and suggest that a lobe moved down from the Straits of Belle Isle, presumably joining the Saint Lawrence glacier west of Cabot Strait.

The writer found evidence on both side of Cabot Strait that the ice lobe had moved through it. At Cape Ray, the southwest point of Newfoundland, striæ pointing on the one hand south 25° east and on the other south 70° east showed that ice had come out of the gulf, passing over this corner of Newfoundland. The glacial drift also indicated by its heterogeneity and by the inclusion of fragments of sedimentary rock that it probably had not come from the crystalline interior of Newfoundland. Saint Paul Island, which stands well out in the strait on the southwest side, showed by its striæ and roches moutonées that ice had moved over it from the west. So far as could be determined from a visit which was cut short by stormy weather and a poor anchorage, there are no glacial boulders on this island. Even at an elevation of 400 feet none was discovered. Possibly the work of the waves in a postglacial submergence has removed them.

Assuming that this Saint Lawrence valley extended across to the edge of the continental shelf, as do many submarine valleys off other coasts of the world at the present time, it would have been quite natural for the glacial tongue to have continued across this depression in the shelf. It is well known that the ice sheets produced a lowering in the sealevel. It is possible that this ice tongue moved across an emerged continental shelf. Even if the shelf were covered with water, the tongue could have moved across it, provided it were about one-eighth thicker than the water depth.

That glacial erosion has been a significant factor in this general area is shown in part by the fiords of Newfoundland. Some of these are over 300 fathoms deep, which is deeper than most Alaskan and Norwegian fiords. The Saguenay Inlet well up the Saint Lawrence estuary is a very good example of a fiord.

Earthquake Evidence

Dr. Keith's preliminary report on the Grand Banks earthquake[8] gives a very interesting account of the accompanying phenomena. This account will be drawn on in considering the relation of the earthquake and the

[7] A. P. Coleman: Pleistocene of Newfoundland. Jour. Geol., vol. 34, 1926, fig. 1, p. 197.

[8] Arthur Keith: Loc. cit.

Saint Lawrence trough. The epicenter has been located near the base of the continental slope outside of the limits of the trough (Figure 2). Practically all the breaks in the cables were also outside of the trough. Gregory [9] contended that the breaks in the cables formed two lines which were continuations of the sides of the trough. Early reports suggested something of the sort, but the more detailed information as plotted on figures 1 and 2 does not bear out this contention. Other earthquakes have occurred off the Grand Banks. Several tidal waves have swept the southeast peninsula of Newfoundland, causing destruction and loss of life. Cables were broken on two previous occasions off the Grand Banks.[10] In each case the breaks were on the continental slopes, but far removed from the Saint Lawrence trough. While a number of earthquakes have occurred in the Saint Lawrence valley, they have been located in all cases above the head of the trough.

The topography of the slopes and of the ocean bottom where both the recent and earlier cable breaks occurred appears to be quite different from that of the trough. The relief in the earthquake zones is infinitely greater. The zigzag bends which the continental slopes make in this general vicinity suggest the intersection of fault scarps. The association of earthquakes and steep submarine slopes has been referred to by many writers, and this association applies also to the Grand Banks earthquake. The question is whether there is any connection between this particular example of a submarine slope earthquake and the trough on the continental shelf inside the earthquake zone.

An analogy might be suggested. Assume that an earthquake occurs at the east base of the Sierra Nevada mountains that causes a series of displacements centering outside a valley which comes out of the range. Can one conclude that the mountain valley is a graben? Certainly no such conclusion is warranted. On the other hand, an examination of the topography and geology of the mountain valley might determine whether or not it were a graben. We can follow this procedure to some extent with the Saint Lawrence trough.

Characteristics of the Trough

General Statement

It remains for us to consider what type of feature, river valley, fault graben, or glacial trough appears to be represented by the Saint Lawrence submarine valley. Although the soundings are not numerous in much of

[9] J. W. Gregory: Op. cit., p. 945.
[10] John Milne: Suboceanic changes. Geog. Jour., vol. 10, 1897, p. 261.

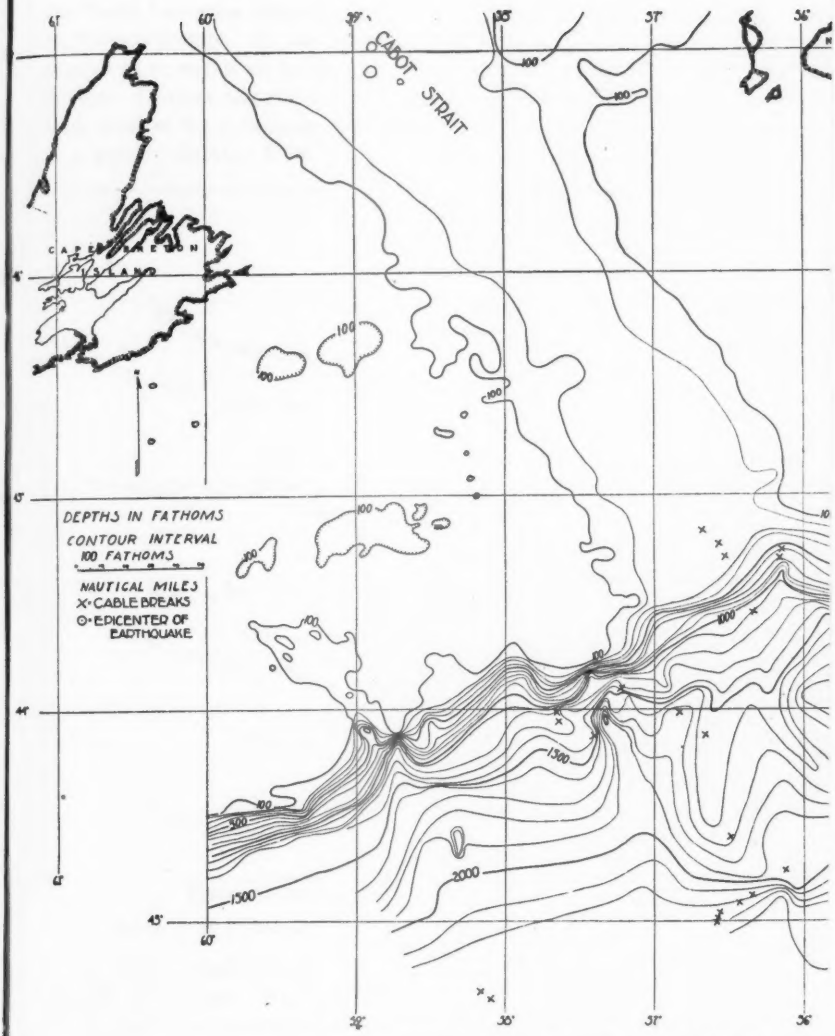


FIGURE 2.—*Outer Saint Lawrence Trough and Zone of Cat*

Source, U. S. Hydrographic Office Chart No. 981. Soundings by U. S. Coast Guard, and 100 fathom line is fairly well established, but the contours on the continental slope are less hundred soundings.

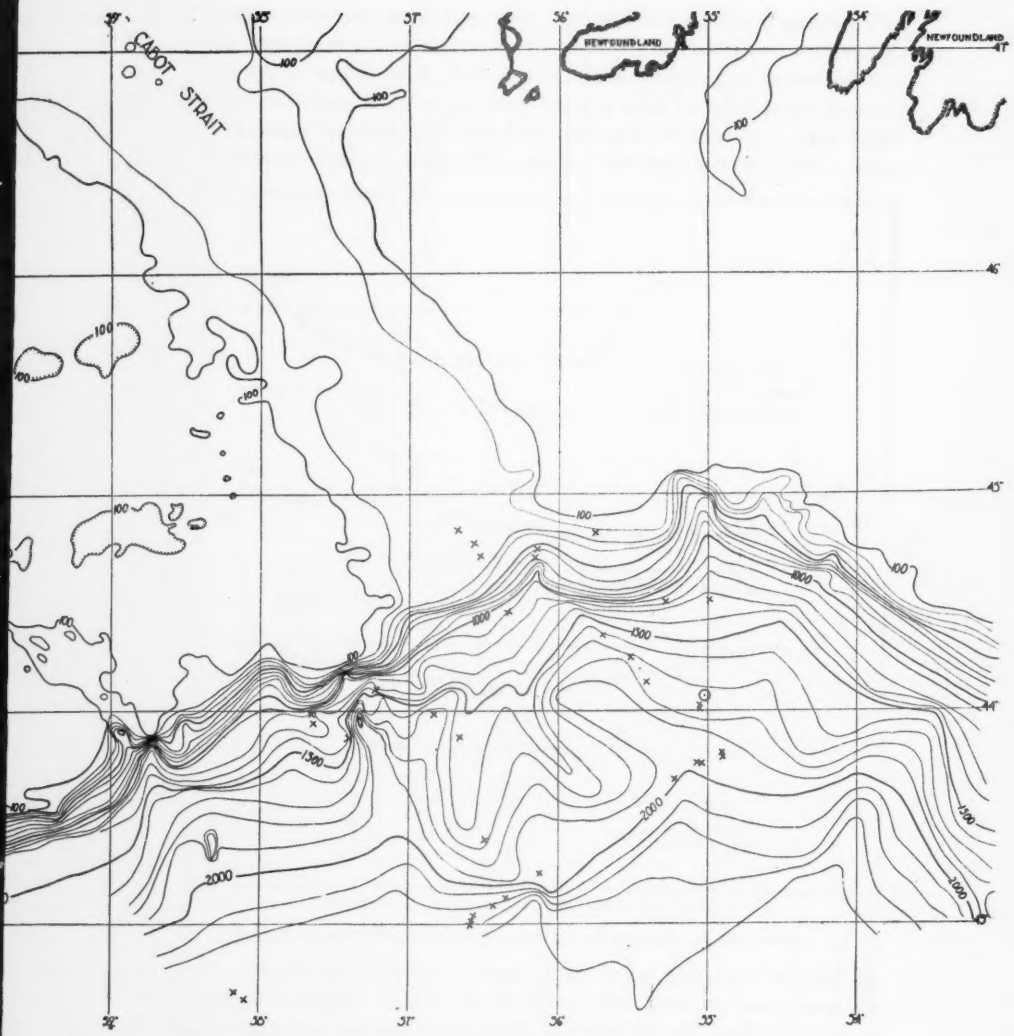


FIGURE 2.—*Outer Saint Lawrence Trough and Zone of Cable Breaks*

ydrographic Office Chart No. 981. Soundings by U. S. Coast Guard, and soundings by cable repair vessels. The airly well established, but the contours on the continental slope are less certain, being based on only about three

the Saint Lawrence waterway, they are sufficient to give a general idea of the topography. In the inner portion of the gulf there are enough soundings to enable us to draw contour maps with a fair degree of confidence. Contour maps of the outer portion must be much more generalized, because the soundings are fewer and also because they were taken at a greater distance from land, making locations less accurate. Even

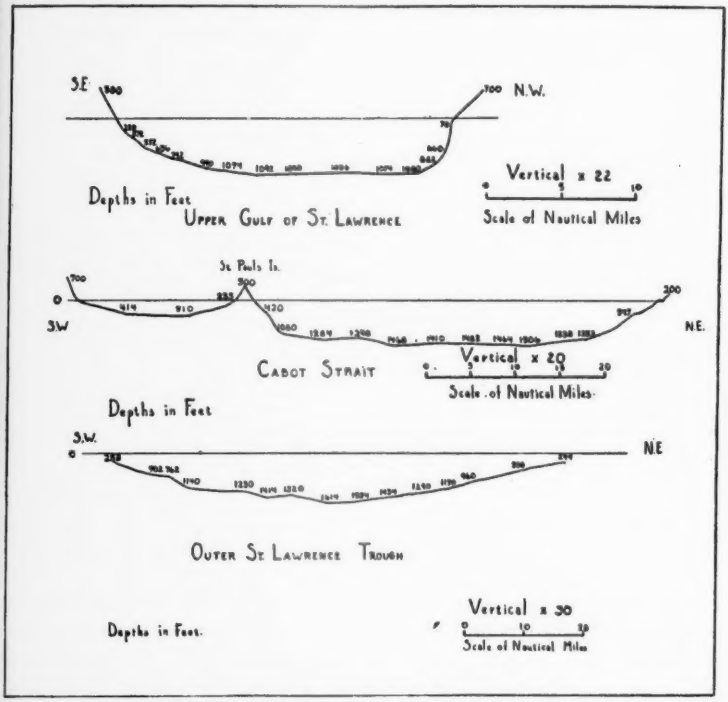


FIGURE 3.—*Profiles across Saint Lawrence Trough*

Source, U. S. Hydrographic Office charts and soundings by the writer.

in the outer trough, however, some of the soundings may be used for scientific deductions. Where the soundings were made in lines across the trough, each line, considered by itself, is probably sufficiently accurate to warrant the drawing of profiles.

If the valley owed its form to river erosion, we might expect to find somewhat sinuous trends, an outward sloping valley floor, tributaries entering more or less at grade, and either a V-shaped or, if in a later stage

of development, a broad flat base.[11] If the form of the valley were due principally to down faulting, the valley would probably have straight precipitous walls, hanging valleys on the side, a tilted floor, fault blocks within the valley, horsts adjacent to it, and a continuation down the continental slope outside. If the trough had been excavated largely by a powerful glacier, it should resemble a fiord in having fairly straight walls, a broad U-shape, hanging valleys on the side, and an undulating floor with basin depressions along its course.

TRANSVERSE PROFILES

The profiles that it is possible to make across this submarine valley

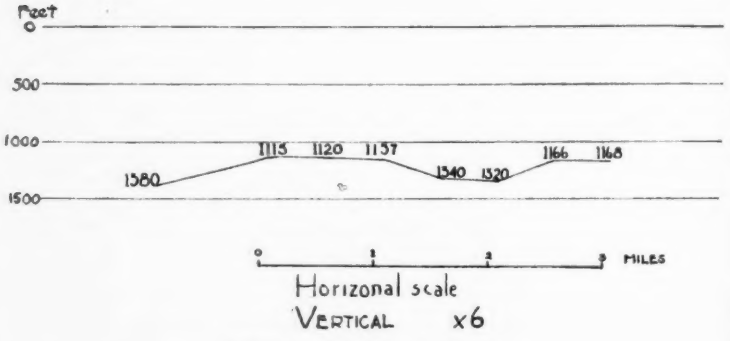


FIGURE 4.—*Detail in the Trough*

The locality is 20 miles southeast of Saint Paul Island. Soundings by the writer.

(figure 3) show a general trough-shape with a wide base of moderate irregularity. The great width of the valley floor, if due to river erosion, would mean late maturity of development and the floor would be rather flat. Details of the floor of the trough examined in several places indicated a hummocky surface (figure 4) very different from that of a river valley in maturity. There are no suggestions of horsts next to the submarine valley nor of fault blocks within it. The profiles are similar to those across the outer portions of typical glacial fiords.[12] The great width is a little unusual for glacial erosion, but there are some fiords almost as wide, and the Great Lakes with greater widths are comparable.

[11] Except along glaciated coasts most of the submarine valleys are roughly V-shaped.

[12] F. P. Shepard: Fundian faults or Fundian glaciers. Bull. Geol. Soc. Amer., vol. 41, 1930, fig. 10, p. 668.

LONGITUDINAL PROFILE

The longitudinal profile along the trough (figure 5) is surely not that of a river valley, nor is it much like that of most fault troughs. The depths, even hundreds of miles from the open ocean, are comparable to those of fiords, and are many times greater than those of such estuaries as Chesapeake Bay, which were probably due to drowning of river valleys. The undulating floor is characteristic of glacially excavated valleys and fiords. Many rimmed depressions are found in the trough. The largest (figure 6) has a length of 90 miles and a depth below its rim of about 390 feet.

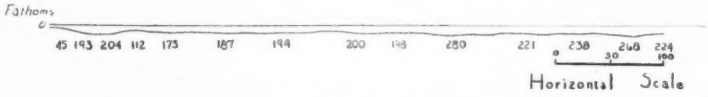


FIGURE 5.—*Longitudinal Profile of the Saint Lawrence Trough*

The area represented is from the Saguenay River to the edge of the continental slope. Soundings in fathoms. Source, U. S. Hydrographic Office Chart No. 1412. Only a few of the soundings are indicated.

TREND

Considering the trend of the submarine valley (figure 1) there is a lack of the sinuosity characteristic of river-cut valleys. The protagonists of the graben hypothesis claim that the faults extend northwest and southeast. Below Anticosti Island the trough runs in that direction, but farther up it has a right-angled bend. If this represents a graben with a right-angled bend it is unusual. On the other hand, the trend does not differ from that in many glacially excavated valleys.

RELATION TO TRIBUTARIES

Along part of the trough the soundings are too scarce to enable us to determine the relation between the submerged tributaries and the main trough, but along the Gaspé coast the relation is very clear. The valleys from the peninsula end abruptly at the straight shore line (figure 7). There is some evidence that the submerged valley coming out of Chaleur Bay has hanging relations to the main trough, and the same is true of some troughs around Cape Breton. On the other hand, some of the tributaries have water in them which is deeper than the adjacent Saint Lawrence trough, as, for example, Despair Bay and Fortune Bay in southern Newfoundland and the Saguenay Inlet far up the Gulf. Clearly this complex relationship is not that of the tributaries of drowned river valleys. The graben theory might account for the hanging valleys, but

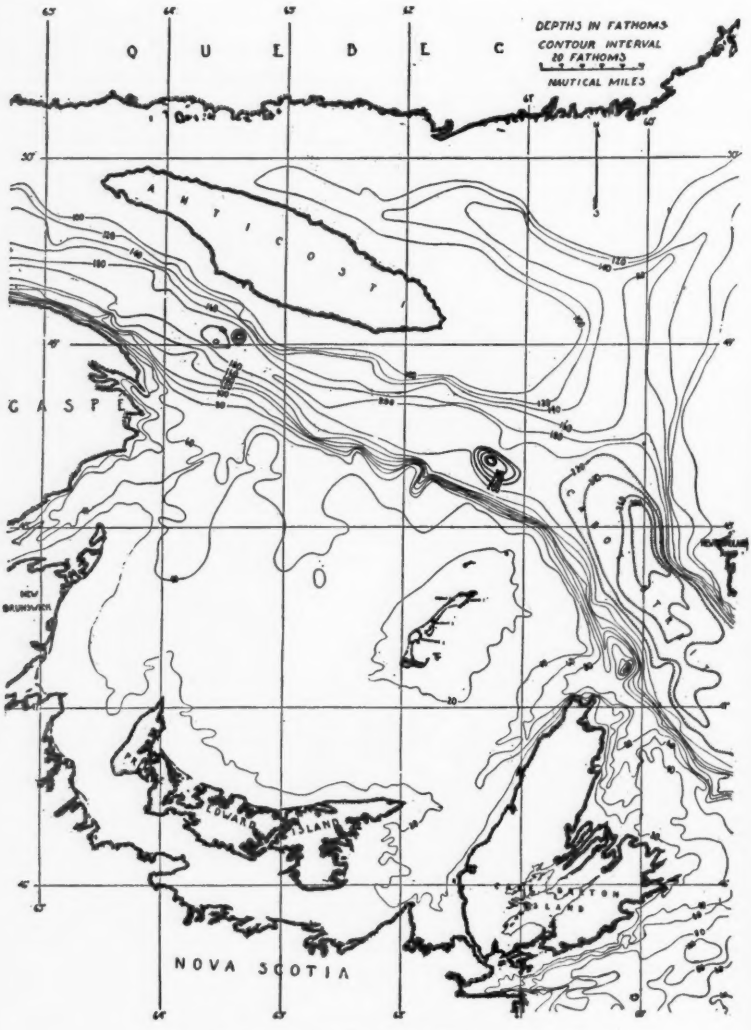


FIGURE 6.—*Portion of the Saint Lawrence Trough*

Showing the elongate rimmed depression inside of Cabot Strait. Source, U. S. Hydrographic Office charts. The contours within the trough are based on about three hundred soundings, but the soundings are scarce in the zone between Cabot Strait and Gaspé Peninsula. The rimmed depressions may have different shapes, but their rimmed nature is clearly established.

hundred and forty-four soundings used to draw the contours.

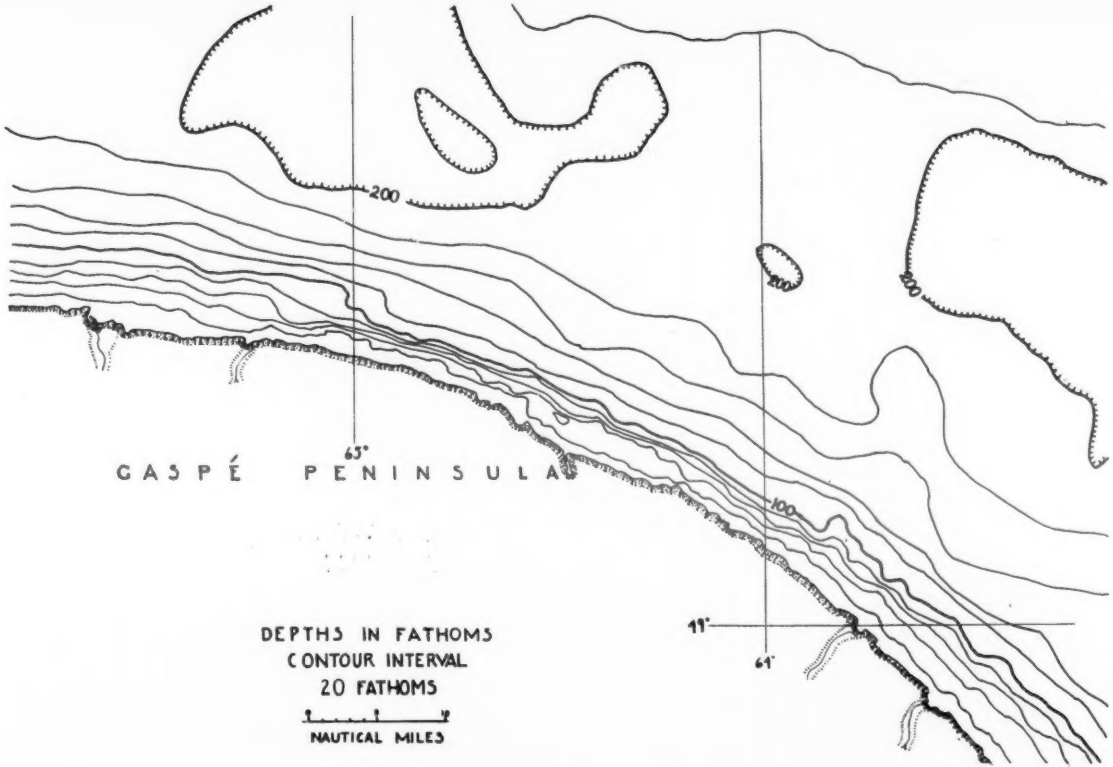


FIGURE 7.—*Portion of the Gaspé Coast*

Showing that the land valleys do not continue down into the submarine trough. Source, Canadian Hydrographic Chart No. 216, five hundred and forty-four soundings used to draw the contours.

the deeper tributaries suggest the work of ice. Tributaries of many Norwegian fiords have greater depths than the main valley,[13] and tributaries of others have the hanging relation.

The inner terminus of the deep trough of the Saint Lawrence is near the mouth of the Saguenay tributary (figure 8). It has been recognized for a long time that the Saguenay was the site of a powerful glacier.[14] Is it not significant that the Saint Lawrence estuary first shows its trough character and great depth below where this glacier entered? This relationship seems to be incompatible with either the graben or river-valley theories.

STRUCTURAL EVIDENCE

The general trend of structural lines in Newfoundland and Cape Breton Island is northeast-southwest. There are a few faults in eastern Nova Scotia and adjacent Cape Breton which trend northwest-southeast.[15] On Saint Paul Island the schistosity was found to run about north 5° west. Minor faults across Cabot Strait in Newfoundland extend northeast-southwest. It is evident that the strait crosses the general strike, but judging from Saint Paul Island, it may cross the strike where the trends are variable, thus enabling erosion to work more effectively. The most that can be said is that no structural evidence yet discovered substantiates the suggestion of faults. It must be remembered that there are many valleys that cross structural trends without visible signs of faults.

Comparison with other Submarine Valleys

Although many writers have referred to the submarine valleys of the continental shelves, there has been little attempt to differentiate the types of these valleys. From studying the soundings whch show these features on charts of all parts of the world, the writer has found that there are at least three different types of submarine valleys: (1) those resembling grabens, (2) those somewhat resembling youthful river valleys, and (3) those resembling glacial troughs. Many of course lack sufficient soundings to be properly classified. The significant thing about this classification is that the graben type occurs off such unstable coasts as Japan, the river type commonly off large rivers, and the glacial type exclusively off glaciated coasts. Of this last type the Saint Lawrence

[13] Examples of these tributaries include Tys Fiord, Trondhjem Fiord, and Samlen Fiord.

[14] Sir J. W. Dawson: The Canadian Ice Age, 1894, p. 178.
Gregory (loc. cit.) claimed that the 1925 earthquake had its epicenter in the Saguenay tributary, but according to Hodgson this is not correct.

[15] Arthur Keith: Op cit., p. 4.

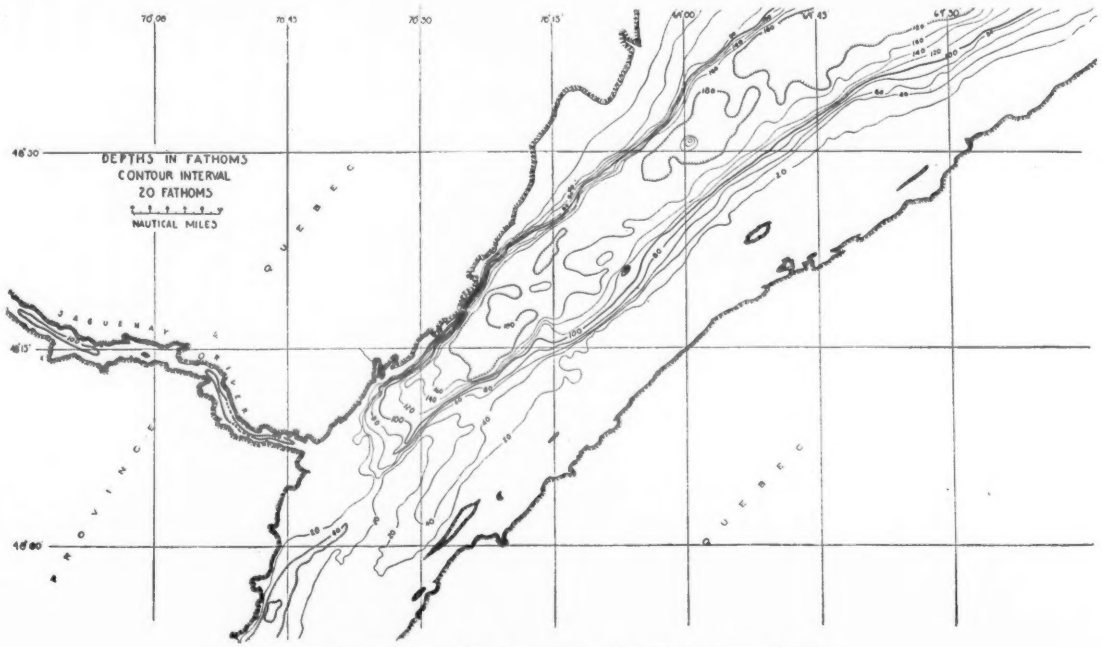


FIGURE 8.—*Relation of the Saguenay to the Saint Lawrence Trough*

Source, Canadian Hydrographic Chart No. 211. Seven hundred and fifty-two soundings were used to draw the contours exclusive of soundings at less than 20 fathoms.

trough is typical, but a few more examples will serve to indicate their general similarity.[16] Beyond the Oslo Fiord extending around the southern coast of Norway, there is an excellent example of a glacial trough (figure 9). Nansen and others have recognized its glacial origin.[17] In western North America we find the same sort of feature coming out of the Juan de Fuca Strait, where a lobe of ice is known to have existed.[18] Farther north, another similar depression comes out of Dixon Strait. This is distinctly a continuation of some fiords of southeast Alaska and British Columbia. Around Iceland there are a number of submarine depressions of this type, most of which extend into fiords of the island. There are also many similar troughs off Norway and Lapland.

Summary

Evidence has been presented to show that the Grand Banks earthquake was associated with the irregular topography of the continental slopes and deep ocean basin rather than with the Saint Lawrence submarine trough, suggesting that the proximity of the trough may be only coincidental. Evidence was also introduced to the effect that glaciers have moved down the Saint Lawrence trough, that the form of the trough is suggestive of glacial erosion, and that similar troughs occur off other glaciated coasts. Therefore, the conclusion seems warranted that the trough has been shaped principally by glacial erosion.

Acknowledgments

The writer is greatly indebted to Mr. Thomas H. Shepard for the use of the yacht *Dorello* on the cruise to Cabot Strait. He is obligated to the United States Coast and Geodetic Survey for the loan of instruments. He also wishes to acknowledge the voluntary assistance rendered during the trip by Messieurs J. H. Harvey, John Schultz, and J. K. Milligan, students at the University of Illinois.

[16] F. P. Shepard: Glacial troughs of the continental shelves. Jour. Geol., vol. 39, pp. 345-360. This gives more detail in this connection.

[17] Fridjof Nansen: Norwegian North Polar Expedition, Scientific Results, vol. 4, no. 13, 1902, pp. 62-66.

[18] J. H. Bretz: Jour. Geol., vol. 28, 1920, pp. 333-339.

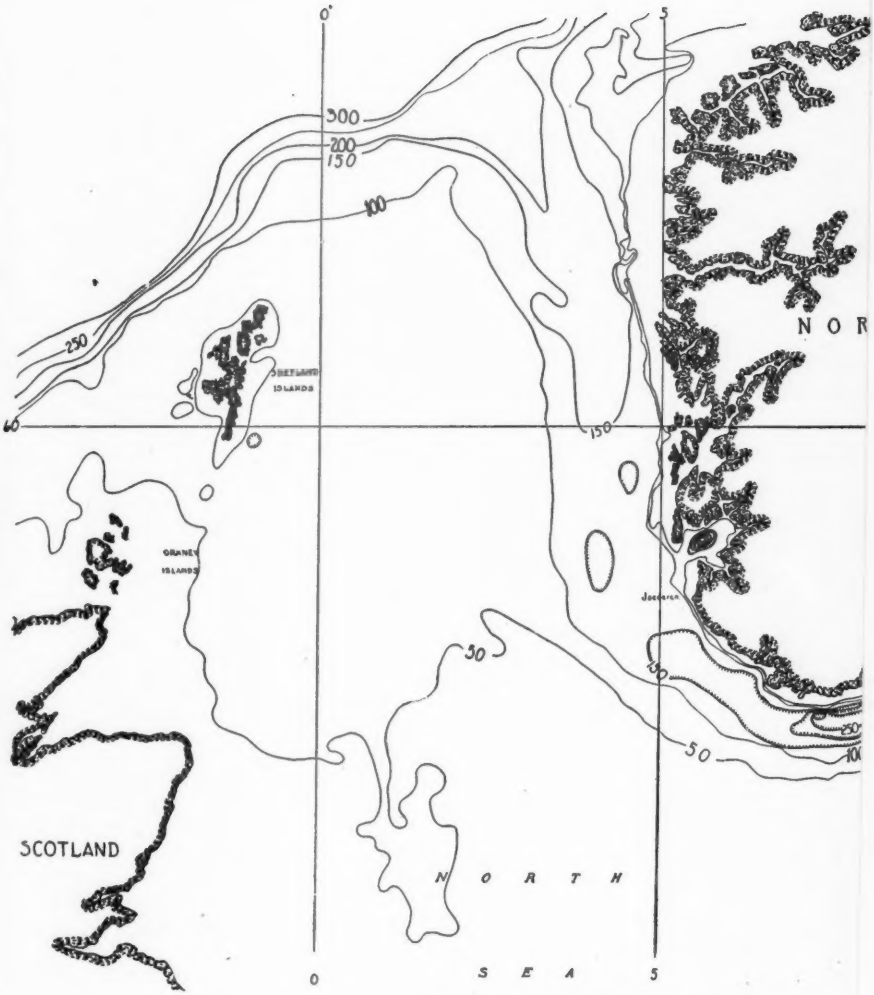


FIGURE 9.—*South Norway Submarine Trough*

Source, U. S. Hydrographic Office charts. Soundings sufficiently numerous to make t

e, U. S. Hydrographi

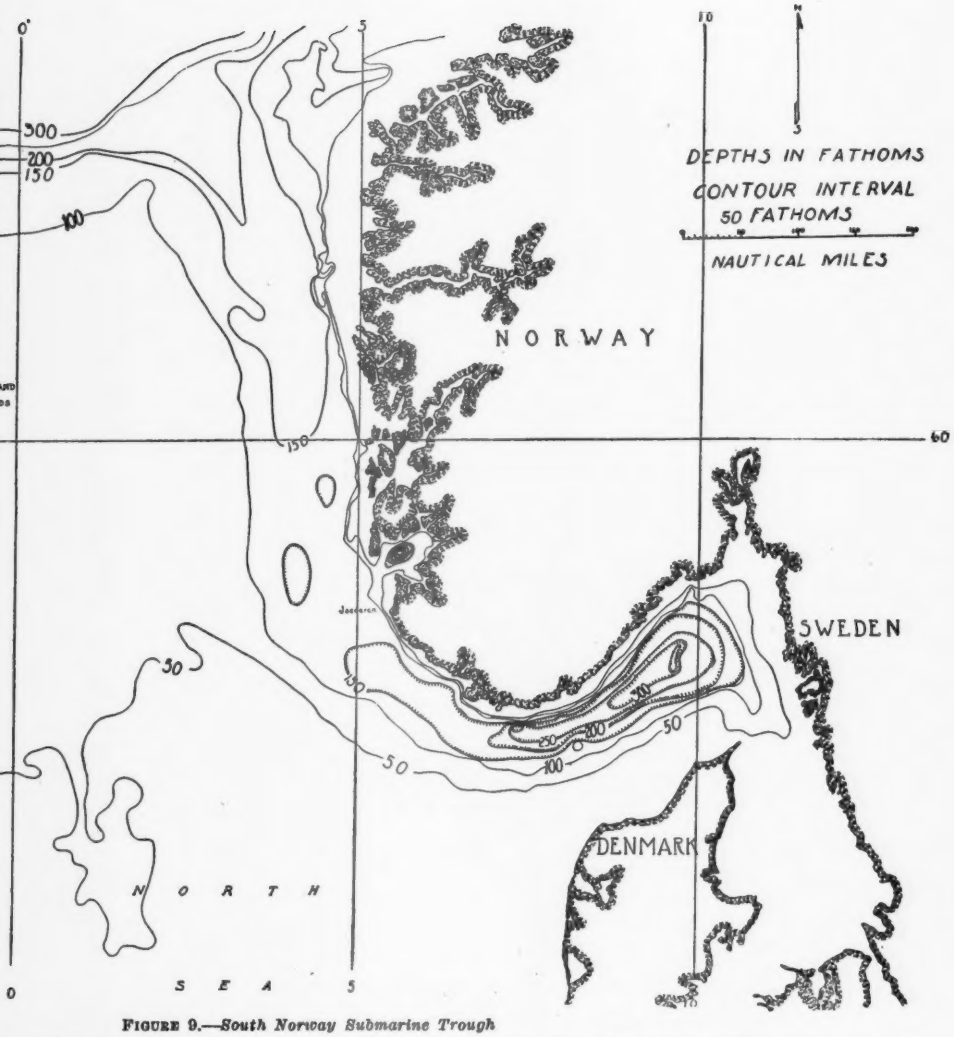
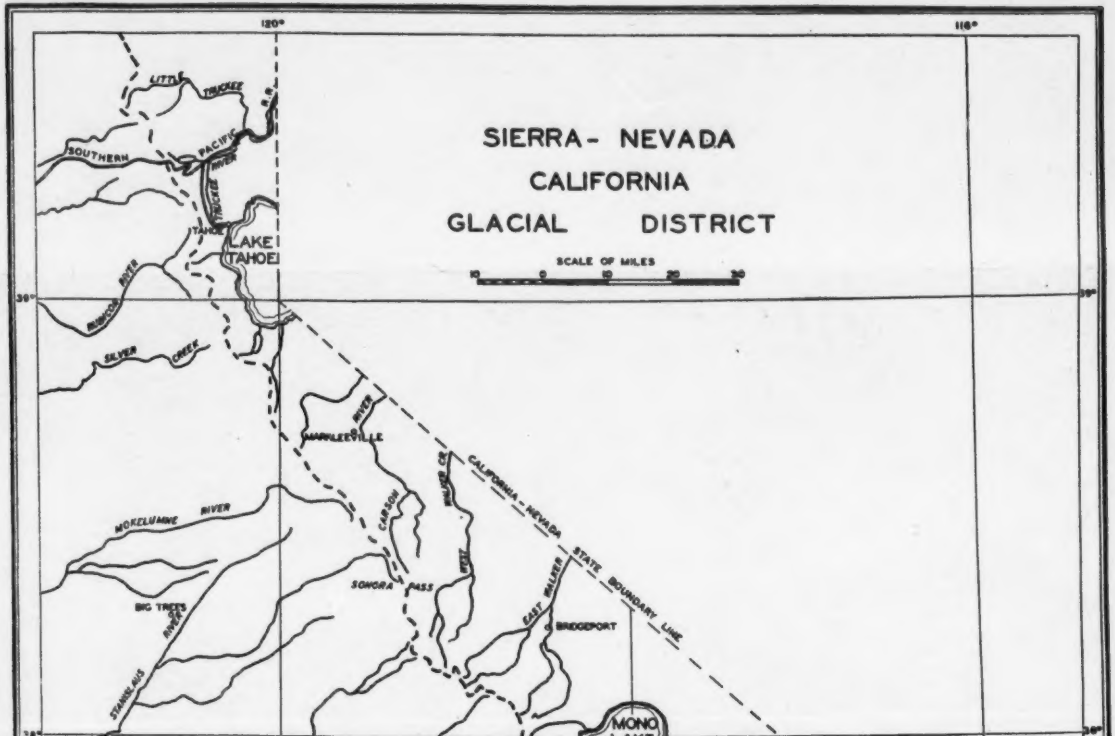
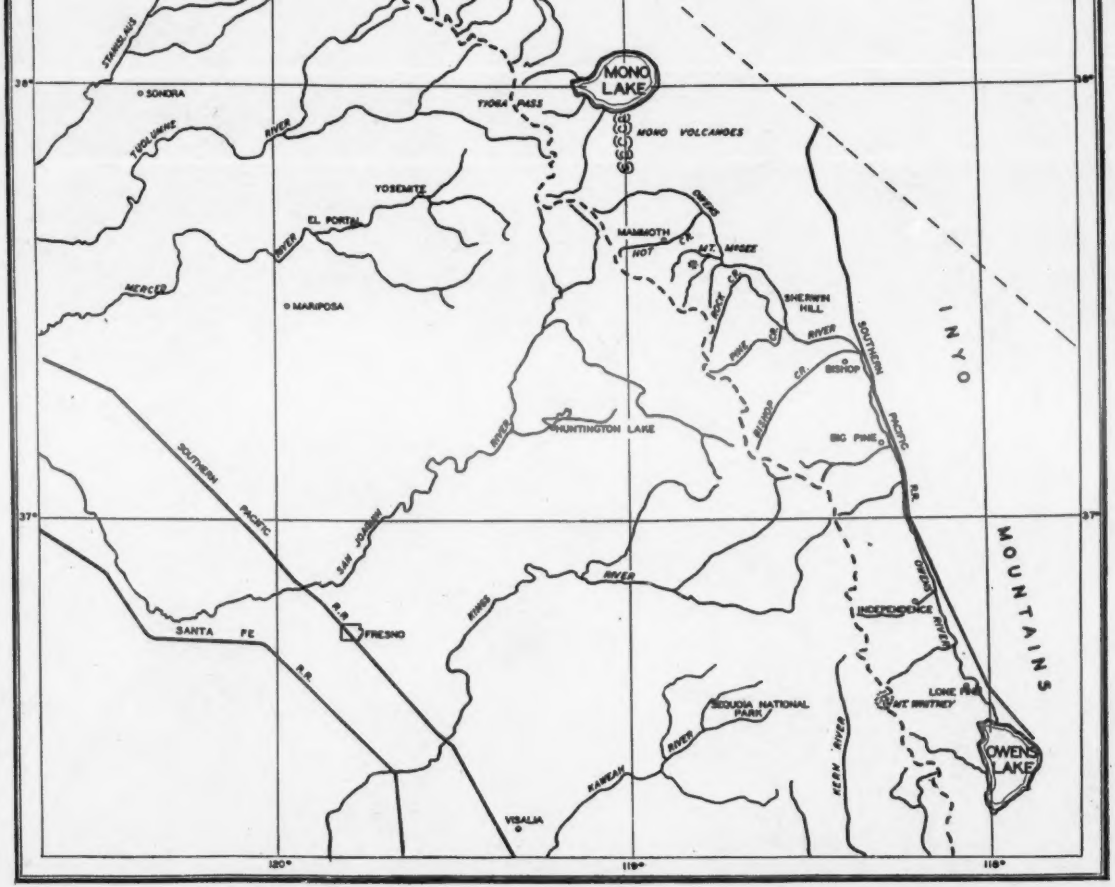


FIGURE 9.—*South Norway Submarine Trough*

Hydrographic Office charts. Soundings sufficiently numerous to make the contours quite accurate.


SIERRA - NEVADA
CALIFORNIA
GLACIAL DISTRICT
SCALE OF MILES
0
10
20
30
120°
116°
39°
LITTLE TRUCKEE
SOUTHERN PACIFIC R.R.
TRUCKEE RIVER
TAHOE
LAKE TAHOE
TRUCKEE RIVER
SILVER CREEK
MARKLEEVILLE
CARSON RIVER
MOKELUMNE RIVER
CARSON PASS
MILLER CR.
CALIFORNIA - NEVADA STATE BOUNDARY LINE
EAST MILLER
BRIDGEPORT
BIG TREES
STANISLAUS RIVER
MONO



MAP OF THE SIERRA NEVADA SHOWING LOCALITIES MENTIONED IN THE PAPER.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 42, PP. 865-922 PLS. 22-23, 31 FIGS. DECEMBER 31, 1931

PLEISTOCENE GLACIATION IN THE SIERRA NEVADA AND BASIN RANGES[1]

BY ELIOT BLACKWELDER

(Read before the Geological Society December 27, 1929)

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INTRODUCTION

Lest the title of this paper may lead the reader to suppose that it contains a detailed account of the glacial phenomena of this vast region, it should be explained at the outset that it is concerned with the general facts of glacial history and the correlation of the events with those already better known in the Rocky Mountains and the eastern States. Although

[1] Manuscript received by the Secretary of the Society May 12, 1931.

the writer has reconnoitered most of the ranges in the Great Basin, he has devoted his attention largely to the study of the dry eastern slope of the Sierra Nevada, where the glacial features are best displayed free from obscuring forests. There he has visited most of the glaciated valleys but has mapped only a few of them in the detail which their interest merits. It will take many years to complete the mapping, and that work will necessarily be done largely by others.

Earlier Work

That the Sierra Navada and other ranges of the West were formerly modified by glacial action was recognized as early as the time of J. D. Whitney (1865) and was a commonplace in the days of the Survey of the 40th Parallel (1871–1878). John Muir (1872) announced that small living glaciers still exist in the high Sierra.

King and Hague (1878) and I. C. Russell (1885) reported the effects of local glaciation in the Ruby, Shoshone, Star Peak, and Granite ranges of Nevada. Others have observed cirques and moraines in the Snake, Schell Creek, and Carson ranges in Nevada, the Onequi Range of Utah and the White Mountains of California. It is probable that most of the Basin Ranges that reach altitudes of 10,000–11,000 feet harbored small glaciers in the later part of the Pleistocene period.

For several decades there was a controversy regarding the effects of the glaciers upon the topography of the range. Some, of whom John Muir was the leader, ascribed to ice action the chief sculptural features of the present scenery. Turner, Matthes, and others, on the contrary, regarded the glaciers as only modifiers of a stream-carved mountain complex. The latter view now prevails.

Current knowledge of the glacial history of the Sierra Nevada has been derived largely from the studies of Russell, Johnson, and Knopf on the eastern slope, and of Turner and Matthes on the western slope. Russell (1889, pages 341 and 392), who was assisted in the field for a time by W J McGee and W. D. Johnson, recognized that there had been three distinct glacial advances, each followed by a retreat, but did not venture the opinion that there were distinct interglacial epochs. He did, however, conclude (page 371) that the two principal advances of the glaciers were contemporaneous with the two high-water stages of Lakes Bonneville and Lahontan. This hesitancy to recognize two distinct glacial epochs is the more strange, because Gilbert (1890), under whose direction Russell has been working, had previously inferred that there must have been two glacial epochs in the Cordilleran region in general. Turner

(1898), in describing the geology of the Big Trees Quadrangle, on the western slope, appears to have been the first to state definitely that two separate stages were recognizable in the Sierra Nevada.

In the years 1905–6–7 Willard D. Johnson, of the United States Geological Survey, made a detailed survey of the glacial features along the east flank of the Sierra Nevada between the West Walker River and Mono Lake. His previous experience in the Mono Lake basin, under the able guidance of I. C. Russell, enhanced his fitness for extending his glacial studies along the range. In the course of this work he recognized moraines of two distinct ages and eroded remnants of till that was much older. On account of his sudden and untimely death, Johnson left no report of these studies and nothing has been published regarding them. His field notes and an excellent series of annotated photographs, preserved in the files of the United States Geological Survey, however, reveal the plain fact that he found and recognized these three glacial stages long before any one else had worked them out. Through the kindness of Mr. F. E. Matthes the writer has been permitted to examine part of the material in the Survey's possession. As the district examined by Johnson is one of the most favorable anywhere in the Pacific mountain belt, it is regrettable that his results were not published at the time.

In 1918 Knopf described the old and young moraines in the Owens Valley section of the eastern front of the range, and added some interesting new proofs of their distinctness. He was the first to publish a map of part of the Sierra Nevada on which the early and late moraines were separately delineated.

The most elaborate glacial study thus far made in the Sierra Nevada has been carried on by Matthes on the western slope, from the Yosemite National Park southward to Kings River. Part of his results are embodied in the excellent memoir (Matthes, 1931) which came from the press after this paper was completed. No report on the glaciation of any other western district equals it.

The existence of three sets of moraines, originally suggested by Russell (1889, page 341), was more definitely announced in 1927, when Blackwelder (1928) presented the evidence for the eastern slope before the Geological Society of America. Matthes (1928) independently published similar evidence for the western slope. In the following year Blackwelder (1930) found deposits believed to represent a fourth and still older glaciation. Evidence already in hand suggests the early realization of Antevs' (1925) prediction that five glacial stages may in time be recognized in the western mountains, corresponding to the five stages in

FIGURE 1.—*Blacksmith Canyon, Southwest of Bridgeport*

The photograph shows bare glacial canyon and ragged granitic mountains (altitude 12,000 feet) of the Tioga stage.

the central plains region of the United States. Assuming that glacial epochs are due to general changes of climate of worldwide influence, it is logical to suppose that similar advances and retreats of the ice occurred in many parts of the globe at the same times.

The writer's own studies have been carried on principally along the eastern side of the Sierra Nevada, from the Truckee Valley on the north to Owens Valley on the south, but they have also included the careful examination of such canyons as the Yosemite, Stanislaus, American, and Yuba on the western slope. The eastern side is a much more favorable place for glacial studies, because it is almost free from the dense forest that hinders geologic observations on the western slope, and there is much less soil on the older moraines. The region[2] around Mono Lake and within 60 miles of it to the northwest and southeast appears to offer the best opportunity for deciphering the glacial history, and therefore the attention of the writer has been concentrated upon that district. From Lake Tahoe northward the forest becomes a serious hindrance on the eastern slope as well as on the west.

FIGURE 1.—*Blacksmith Canyon, Southeast of Bridgeport*

The photograph shows bare glacial canyon and ragged granitic mountains (altitude 12,000 feet) of the Tioga stage.

EASTERN SLOPE OF THE SIERRA NEVADA

VALIDITY AND NUMBER OF THE GLACIAL STAGES

It has been suggested that the Pleistocene period on the Pacific slope comprised only one glacial epoch, but that there were notable retreats and advances of the ice within that single epoch. Under this view, even modern times might be considered a part of the glacial epoch, since a few of the Sierra Nevada glaciers have not entirely disappeared but have merely shrunk back into their cirques. Mount Shasta and other high peaks farther north harbor glaciers of considerable size, and in Alaska there are great ice tongues much larger than any that existed in the Sierra Nevada, even during the time of severest glaciation. The difference of opinion is more apparent than real. It is only a matter of definition or viewpoint.

Since it seems not improbable that the Pleistocene period will in time be divided into several epochs of widespread application, as recently suggested by Eaton (1928) and others, the writer will use at present the terms *age* and *stage* for the times and deposits of the major individual glacial and interglacial advances and retreats. A glacial age will be regarded as a time when many of the deep canyons of the Sierra Nevada were occupied by long tongues of ice. An interglacial age, on the con-

[2] Shown on Pyramid Peak, Markleeville, Dardanelles, Bridgeport, Mount Lyell, Mount Morrison, Mount Goddard, Bishop, and Mount Whitney quadrangles, of the U. S. Geological Survey's Topographic Map of the United States.

trary, was a time when such glaciers shrank to mere vestiges or entirely disappeared. The main canyons were then occupied by lakes and streams, and the activities of glaciers became negligible, although remnants of them may have existed in the valley-head cirques.

It has also been objected that the time between the last two ages recognized in this paper was so short that they should be regarded as merely two subdivisions of one age, but geologic ages have no standard length. In general, the later periods and epochs of Earth history are progressively shorter, because their events can be elaborated in more detail. Adhering to the definition of glacial and interglacial ages stated above, the writer recognizes four ages of glaciation, frankly admitting that they were not equally spaced in time. In so doing he is following the current usage of the central and eastern United States.

Although the district has been carefully studied at the more favorable localities, so that the four glacial epochs in the Pleistocene period in California may be clearly distinguished, a much larger amount of detailed work remains to be done before all the individual glacial features can be classified according to their age and a complete historical map compiled. In this paper it is purposed to explain the evidence on which is based the general conclusion that we may divide the glacial period in the Sierra Nevada into four and perhaps five ages. It is not an exhaustive report on the glaciation of the region.

The four glacial stages now recognized are herein designated by local names which will permit the addition of others that may be discovered later, as a numerical series would not, and on the other hand will not arouse controversy regarding correlation, as would the use of such terms as "Wisconsin," "Iowan," or "Kansan." In stratigraphic order, these stages are:

4. **Tioga stage**
3. **Tahoe stage**
2. **Sherwin stage**
1. **McGee stage**

If a fifth glacial stage is eventually differentiated, evidence now in hand suggests that it will lie between the Sherwin and Tahoe stages of the above table. The best localities for the study of this evidence are southwest of Mono Lake, near the fork of West Walker River and near Truckee.

CRITERIA OF AGE

In differentiating the glacial stages of the Sierra Nevada many kinds of evidence have been used. Some of the criteria that are commonly

utilized in the eastern United States have been found to be of little value or of only local applicability in California, but fortunately others have been found to take their places. For example, the soil profile is so in-

FIGURE 2.—*Talus-filled Glacial Valleys of the Tahoe Stage*
Locality is northwest of Mount McGee. Photograph by George L. Green.

completely developed in the semiarid regions that instead of being one of the chief reliances of the glacialist, as it is in Iowa and Illinois (Kay, 1929; Leighton and MacClintock, 1930), it has not yet been found to give decisive results in the West. No old interbedded soil zones or sheets of

loess and no interglacial fossils have thus far been found in the region. On the other hand, topographic relations, the progress of decay of glacial boulders, and erosional forms have proved to be much more serviceable in California than in the plains that were covered by the great ice sheets. Altogether about 20 distinct criteria have been used in the field during the study of this subject. It seems advisable to explain them somewhat fully at this juncture, so that other students of the region may understand the basis of the opinions expressed later in this paper. Most of the criteria depend on the changes that have taken place since the glacial action ceased. Others have to do with the relations of the glaciers to other features, such as lakes and volcanoes.

FIGURE 3.—*Glaciated Surface of Granite, of the Tioga Stage*
The glass-like polished surface has been partly destroyed by some process of exfoliation. (Six-inch scale against boulder.)

In general, it has been found that the moraines of each of the several stages were less extensive than those of the next preceding. Hence, in a particular valley the moraines nearest the head are the youngest and those farthest out are commonly the oldest. It has also been found that the

moraines of the latest stage were generally puny in size as compared with the bulky embankments of the Tahoe stage. These criteria, however, are not decisive. They are merely suggestive.

The advance of talus cones, especially in the cirques, is a criterion of some value in differentiating the last two stages, but is useless for earlier times because the older cirques have been destroyed by erosion. It is essential in each case to consider the kind of rock and the joint systems. One should compare only cirques of similar lithology and structure or else make due allowance for the differences. A young cirque in closely

FIGURE 4.—*Leavitt Creek, East of Sonora Pass*

The photograph shows a gorge eroded to a depth of 35 feet in well-jointed granite since the Tahoe age.

jointed lava or slate may contain more talus than an old cirque in massive granite, because the rate of talus formation is very different in the two cases.

The fresh ragged appearance of cirques is a related criterion subject to much the same limitations. Allowing for lithology and jointing, the older cirques are decidedly less craggy and wildly picturesque, have more soil and hence more vegetation upon their slopes. One speaks of them as being subdued.

The preservation of polished and striated rock surfaces on roches moutonnées and elsewhere is a useful criterion if applied with careful regard to the nature of the rock and the extent to which it has been exposed to destructive surface agencies. Dense siliceous rocks preserve striæ and even polish for vast lengths of time, while such rocks as granite and marble lose them quickly by weathering. A cover of only a few inches of soil protects against forest fires, which are by far the most destructive agent of

FIGURE 5.—*Postglacial Notch in a Terminal Moraine of the Tioga Stage*

The locality is Leevining Canyon, near Mono Lake. The stream passes through to the right of the sharp bend in the road. In the rear a huge lateral moraine of the Tahoe stage extends across the view.

weathering in the mountains, but such a covering favors chemical alterations. Allowing for the variables, one may say that striated surfaces of Tioga age are extensively preserved even on granite, whereas those of Tahoe age are seldom preserved on granite but are well retained on quartz and aplite veins, quartzite, hornfels, and the harder slates. Glaciated rock surfaces of still earlier ages have rarely been found on the western slope, although striated boulders are locally rather common in fresh excavations.

The depth of valleys cut by axial creeks in the glacial floor is a criterion of importance, but one that likewise must be used with discrimination. Creeks of different sizes and gradients excavate at different rates. They

may sink their channels deeply in till, not so deeply in jointed lava, and only slightly in massive granite that has widely spaced joints. Extensive observations enable one to judge whether the gorge cut by a certain stream under the local conditions is appropriate to the duration of post-Tioga or post-Tahoe time. No general rule can be given.

The extent to which the terminal moraine has been destroyed by the axial stream in widening its flood plain after it has cut down to grade (profile of equilibrium) is a significant type of evidence related to the last one. Generally the Tioga moraines have been merely notched and the axial creeks are still above grade. The Tahoe moraines have, on the other hand, been breached more or less widely and in many cases the frontal part has been entirely consumed in the development of a spacious flood plain. As in the preceding case, the local factors must have due consideration, for they modify the results.

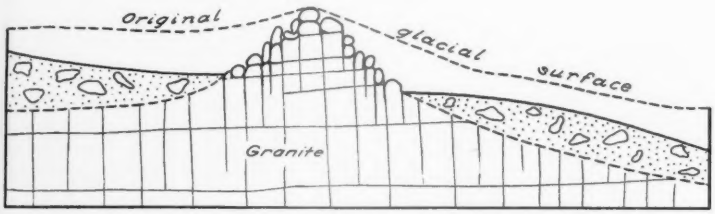

FIGURE 6.—*Diagram of a Granite Knoll*

This knoll has been developed by erosion and weathering on the site of a till-veneered rock mound which has not been glaciated since the Sherwin epoch. The locality is Dog Creek, south of Bridgeport.

The general extent of valley growth in the moraines is one of the most useful considerations. Near large streams and on steep slopes ravines advance rapidly in till. A moraine with but few short ravines is probably younger than another of broad gentle contour into which long graded branching ravines have advanced. In general the Sherwin till has been maturely dissected, but the Tahoe moraines still retain most of their distinctive glacial features.

The wastage of moraines by the complex action of weathering, wind, and rain-rills tends to leave rocky knolls standing out from their surfaces. Such crags of granite are rather common in areas of Sherwin till which have probably lost much of their original thickness by wind and rill action. They are lacking in the younger moraines or appear only as rounded ice-scoured mounds.

The destruction of lakes, either by lowering of outlets or by the advance of deltas, has made little progress since the last glacial age, but since Tahoe time it has been almost completed. The lakes of the latter age are now represented by gravelly plains more or less intrenched. Still older lakes can be recognized only by their deposits, since their original topography has been quite destroyed by erosion.

The depth of wind-laid deposits on moraines is locally of value in distinguishing different stages. Near Mono Lake a linear row of obsidian

FIGURE 7.—*Top of Hunnewill Hill near Bridgeport*

The boulders of andesite were drilled and grooved by sandblasting during the Tahoe age. The wind came from the right.

volcanoes was formed by eruptions in the Pleistocene period. Copious showers of ash and pumice lapilli were then scattered for many miles. On the youngest moraines in the vicinity there is but little ash, except very near the cones, where it may exceed 2 feet in depth. On the next older moraine there is a thicker coat (2–7 feet) and on the Sherwin till there is locally enough (6–20 feet) to obliterate the morainic surface. Elsewhere the fine "soil" that mantles the Sherwin till in many places, in contrast with the Tahoe and especially with the Tioga moraines, is probably loessial in large part and its thickness is a rough measure of age. This criterion has not yet been much applied in the West but seems to offer some promise.

Weathering of the till is a familiar indication of age but one that has been much less used in the West than in the East. It is probably worthy of more study than has been given it thus far. The western tills are not so calcareous as those in the East and hence acid tests for leaching have not given significant results. The aridity in most parts of the West inhibits the development of a true soil profile; but on the moist western slope of the Sierra Nevada the Sherwin till has weathered to a somewhat rusty or tawny hue as compared with the light-buff color of the Tahoe till and the ashen gray of the youngest till. The depth to which the reddening has penetrated has not been satisfactorily determined.

FIGURE 8.—*An Area Southeast of Fales Hot Spring, West Walker River*

The area shows scarcity of boulders on the maturely eroded surface of an ancient moraine of the Sherwin stage. The granite crags in the rear may be in part outside the glacial limit.

Weathering of boulders in the till is, however, one of the criteria that was found most useful in this investigation. Since the weathering of such rocks as quartzite, basalt, slate, granite, and marble can not be readily compared, it was found best to concentrate attention on a single type of rock—the average granodiorite of the Sierra Nevada batholith. Fortunately this occurs abundantly in most of the tills in the region. Boulders of this rock were then counted at certain places and classified as being (*a*) almost unweathered, (*b*) notably decayed on the surface but still solid, (*c*) greatly weathered, cavernous, or rotten. These figures constitute a ratio known in the field as the G. W. R. or "granite weathering ratio." A ratio of 90–10–0 would be sure indication of the latest age; one of 30–60–10 would be typical of the Tahoe stage; while one of 0–30–70 would be afforded by only the older tills. These ratios were found to apply in nearly every locality, but it was noted that on the moist western

slope of the Sierra Nevada decay has gone farther, and so the proportion of decayed boulders there is slightly greater in each stage than it is in the more arid regions. Since forest fires have done great damage in these wooded mountains and since fire shatters boulders rapidly and severely, one must learn to distinguish the effects of fire from those of chemical decay and consider only the latter in his classification for this purpose.

FIGURE 9.—*View South of Lake Tahoe*

Showing abundance of boulders on a low moraine of the Tioga stage.

The effects of the sandblast (Blackwelder, 1929) on boulders of the Tioga stage moraines are generally slight, but locally where such effects appear they are still fresh. On the Tahoe moraines many boulders properly situated with reference to wind exposure are notably chiselled by the sandblast, but the worn surfaces are now dull, partly crumbling, and somewhat exfoliated. On the Sherwin till similar surfaces are much more weathered. Although the sandblast may have operated at various times there is strong evidence to show that the rocks were generally carved during the presence of the glacier that made the moraine.

The frequency of boulders on the undisturbed till surfaces is a criterion of less value than weathering but is useful because it can be observed at long range and even in photographs. In general, the younger moraines are more bouldery than the older ones. In order to reduce this general

FIGURE 10.—*Lakes of the Tioga Stage*

Originally there was only one lake, which was held in by a low frontal moraine. Later the advance of mudflow fans from the adjacent lateral moraines constricted the valley and thus formed Twin Lakes, near Bridgeport. The large lateral moraine on the right belongs to the Tahoe stage.

fact to at least a rough quantitative basis, many counts were made along measured straight lines which could be easily reduced to terms of area. Thus, 34 boulders in 850 feet indicate 75 boulders per acre. Arbitrarily the count was limited to boulders over 1 foot in diameter. In regions of closely jointed rocks boulders are fewer than in those of massive blocky rocks. In certain topographic situations, as on the ridge crests and terrace brinks, boulders are relatively more abundant, because the earthy matter tends to be swept away from them. Boulders in depressions tend to become buried by the same process. These and other modifying factors will occur to the careful field student. By using due care the value of this criterion may be preserved. It is easy to apply and is generally available.

Much significance can be derived from the relations between the glacial features and other physiographic forms about which some age information is already available. Thus the shore terraces carved on the Tahoe moraines by the waves of greater Mono Lake show that the moraines are older than the last rise of the lake. The deltas made in the lakes can in some cases be traced back to a moraine. In a few places small faults cut the moraines or are covered by them. Near the Mono volcanoes a lava flow has poured down over a moraine and in other places moraines have been plastered upon lava flows of interglacial age.

The most useful criterion of this kind is the stream terraces that have been formed as a result of the aggrading and subsequent trenching of glacial valley trains. A careful study and measurement of these terraces showed a surprising uniformity for the several ages. The post-Tioga terraces are generally 15–30 feet high and the post-Tahoe terraces 50–75 feet. The still older terraces are harder to trace, but are usually much higher. On account of the length of the terrace systems it may become possible, by the careful tracing of them, to link them to other features, such as distant lakes, deposits of known age, and volcanic outflows. The study of these terraces has only begun.

Of all these criteria only a few can usually be applied in any one place. One of them alone affords only a tentative opinion, but when several of them all point to the same conclusion confidence is much strengthened.

RELATIVE LENGTHS OF THE AGES

There is no basis thus far for estimating in terms of years the times represented by the various glacial and interglacial stages. The best that can be done is to consider the lapse of time since the latest glaciers built their terminal moraines and to estimate roughly the duration of the other ages in terms of that unit.

So fresh and unaltered are the moraines and rock-scoured surfaces of the Tioga stage that one can not allow many thousands of years for the postglacial age. If one accepts the conclusions of De Geer and Antevs (1925) and the correlation of the Tioga with the Wisconsin and Würm stages, then the time since the retreat started may have been about 25,000 years and the present condition of deglaciation may have endured some 10,000 years.

The interval between the Tahoe and Tioga ages was estimated by Knopf (1918) to be about five units and by Miss Russell (1925) to be about two and a half units. Judging from the depth of erosion in rock by the axial creeks, the writer favors the former estimate rather than the latter.

The interval between the Sherwin and Tahoe stages has apparently not been estimated by any one thus far. All the evidence indicates a much longer time than the post-Tahoe interval. It seems more probable that it was of the order of 50 units rather than less.

The post-McGee interglacial age permitted the excavation of great mountain canyons several times as deep and spacious as those of the post-Sherwin age. Judging from this and the nearly complete destruction of the moraine system, the writer is disposed to consider this earliest interglacial age to have been about three to five times as long as the one following the Sherwin stage, or perhaps 150–250 units.

It will be readily conceded that very little confidence can be placed in such estimates, and yet they have their value in adding a certain amount of perspective to the historical view.

So closely are the Tioga and Tahoe stages related in time and in other respects that they might well be bracketed together as subdivisions of a single epoch. Such a course is urged by Matthes and others, while similar plans have been proposed recently by Kay (1931) and Leighton (1931) for the Iowan and Wisconsin stages of the central United States. It has the merit of indicating the fact of closer relationship.

GLACIAL STAGES ON THE EAST SIDE OF THE SIERRA NEVADA

Tioga stage.—Because it is best understood and may therefore be used as a basis for comparison, the latest age will be discussed first. In view of the possibility that still other ages may eventually be added to the four now recognized, geographic names have been adopted for them, in preference to the numbers which would otherwise be more convenient.

The latest of the four stages here recognized is so clearly identical with the Wisconsin, as defined in the Rocky Mountains and in the eastern

United States, that Matthes (1931) has adopted that name for the latest epoch in the Yosemite region. For the present, however, it seems best to retain a local name; and none of the names available seems more suitable than Tioga, for a glacier of this age occupied Tioga Pass and its lobes descended both southwest and northeast therefrom, leaving characteristic moraines and lakes. East slope localities where the moraines of this epoch are well displayed are Convict Lake, June Lake, Grant Lake, Leevining Canyon, Twin Lakes (Bridgeport Basin), Fallen Leaf Lake, and Donner Lake west of Truckee.

The glacial features that were made by the ice tongues of the Tioga epoch are even now almost as fresh and unaltered as at the time of their formation. The cirques are still as bare and ragged as if recently abandoned by the ice. Talus cones are few and small where the rocks are not closely jointed, and have not grown to large size even where the closer spacing of joints is favorable to frost action. The original polished and striated surface is still rather generally intact, even on such easily weathered rocks as coarse granite. Acres of polished and grooved rock are a familiar sight near Tenaya Lake (Yosemite National Park) and many other places in the high Sierra. If it were not for the destructive effects of forest fires, such surfaces would be even more completely preserved.

The lateral moraines generally stand out as bold embankments, marred only by a few landslides and by sharp ravines where tributary brooks descend the canyon sides. The terminal moraines are still complete, except for V-shaped notches through which the main streams tumble down to the plains beyond. As the distinctive glacial topography of the moraines is almost entirely preserved, it is generally an easy task to map them continuously.

Most of the valleys that were inhabited by glaciers of the fourth epoch now contain clear lakes 50 to 300 feet deep, some of which are a mile or more in length. The bouldery slopes commonly descend steeply into the water. Deltas at the upper ends of these lakes have grown forward only a small fraction of the original length of the lake, and the outlet streams have incised their morainic dams only 10–75 feet. Fallen Leaf Lake, near Lake Tahoe, held in by a compound loop of terminal moraines, is the largest lake of this type on the eastern slope of the range. Independence, Convict, and Donner lakes are similar. Only a few of the smaller and shallower lakes of this age have already disappeared. The rock-bound mountain tarns in the upper parts of the glacial troughs, largely surrounded by bare ice-scored rock mounds, are in substantially the same condition now as when the glaciers left them.

Typically the moraines of the Tioga epoch are very bouldery. The boulder frequency[4] averages about 2,000 (300–7,000) per acre. This excessive abundance of boulders on the surface is probably to be explained partly by the fact that few if any of them have been disintegrated by weathering, but chiefly by the fact that so little windblown dust has been deposited in postglacial time that the smaller boulders have not been buried.

Chemical weathering has made but little progress since the Tioga stage. Even among the granodiorite boulders many still retain striated surfaces, and about nine-tenths of them have suffered very little external change except where forest fires have shattered them. The fresh appearance of the average light gray granitic boulders, without rusty discoloration, soon becomes familiar. The color of the till itself is ashy gray, rather than buff or rusty as it is in the older tills.

In suitable situations, boulders of the Tioga stage have been slightly grooved and polished by sandblast action. Such surfaces are relatively fresh in appearance as contrasted with those on the Tahoe moraines.

In contrast to even the ravines which the axial streams have excavated in the till, are the narrow slots, only 1 to 8 feet deep, that they have worn in the bed rock, and even these narrow chanels may have been excavated largely by streams issuing from the ends of the glaciers during their final retreat. Such turbid streams must have been much more active rasps than the clear brooks that now occupy these channels.

In the canyons beyond the termini of the Tioga glaciers, gravel trains were built and later intrenched. The terraces thus formed are more continuous than any older ones and generally stand only 15–25 feet above normal stream-level. These lowest terraces have in several instances been traced directly into the Tioga stage moraines. The relations are well shown west of Truckee and southwest of Bishop. An exception is to be noted in Mono Valley where the fall of the lake surface some 600 feet on account of excessive evaporation caused a correspondingly greater intrenchment of the glacio-fluvial deposits.

The volcanic activity, of which there is abundant evidence in and south of Mono Lake, seems to have ceased almost entirely before the last glacial epoch. As shown by Russell (1889), there are a few small pit craters and low cones that appear to be very recent, and the one at the north end of the Mono volcanic chain was clearly formed after Mono Lake receded from its highest level. Since this expansion of the lake is reasonably to

[4] By this is meant the number of boulders over one foot in diameter actually exposed on the surface, per acre. See page 880.

be correlated with the Tioga glacial epoch, these youngest craters may be regarded as postglacial in age. Unlike the older moraines of that district, the youngest moraines have so little volcanic ash upon their surfaces that it appears to form a layer of appreciable thickness in only a few localities near the Mono cones. Northeast of June Lake, road cuts show that the coat of ash is as much as 2–4 feet thick.

The glaciers of the Tioga epoch were smaller than their predecessors, and so their moraines are now generally found arranged concentrically within the earlier moraines of the Tahoe stage. The average relief of the moraine fronts is about 25 feet. Few are more than 75 feet and some are hardly 10 feet high. Being much less conspicuous, these younger moraines have often been overlooked or regarded as mere recessional loops related to the great laterals which are here referred to the preceding Tahoe stage. A rough estimate of relative bulks indicates that the great Tahoe moraines of Bridgeport Basin contain about 50 times as much material as the Tioga moraine loops in the same valley.

Although some of the Tioga stage glaciers on the western slope descended to elevations less than 6,000 feet above sealevel, those on the dry eastern slope were unable to creep down so far, partly no doubt because the climatic conditions were much less favorable to glacier growth than on the west side, but partly because the base of the range stands, in most places, above 6,000 feet. The average elevation of the ends of fifteen terminal moraines of this epoch along the eastern side of the Sierra Nevada proved to be about 7,500 feet and the lowest one thus far examined by the writer (Big Pine) extends down to about 5,750 feet above sealevel.

Tahoe stage.—The most conspicuous moraines in the Sierra Nevada are those of the Tahoe age. They are well developed and easily studied in the Big Pine, Bishop, and Pine Creek districts of Owens Valley and in nearly every important canyon northward to Truckee and beyond. In general, moraines of this age have been recognized in all the valleys that also contained glaciers of the Tioga age and also in some that did not. One of the most favorable localities for the study of such moraines is west and south of Mono Lake. The name is derived from Lake Tahoe, along the western shore of which several large glaciers of this age descended from the Sierra Nevada and built strong moraines. Lake Tahoe itself is, however, not of glacial origin.

The primary glacial features of the Tahoe epoch are still fairly well preserved and are easily recognizable, although they have been notably marred and obscured by the processes of weathering, stream erosion, and deposition. The fact that they are generally associated closely with the

FIGURE 11.—*Robinson Canyon near Bridgeport*

The view shows a frontal moraine of the Tioga stage (XX) only 30 feet high, with a 700-foot lateral moraine of the earlier (Tahoe) stage on the left.

FIGURE 12.—*Lacustrine Terraces of post-Tahoe Age*

The locality is the front of the Sierra Nevada west of Mono Lake. A long moraine tongue (A) protrudes from Lundy Canyon. The waves of Mono Lake during the Tioga stage engraved six or more terraces upon the flanks of the moraine. Much older till of the Sherwin stage appears on the rocky spurs to the right (X).

corresponding features of the Tioga epoch facilitates comparisons between the two. Even so, close scrutiny is often required to distinguish them. Some observers have been so impressed with the close relations between the Tioga and Tahoe stages that, although conceding the differences, they have preferred to regard them as one stage with two advances separated by a retreat. Knopf (1918) and others have, however, considered them distinct.

Many of the cirques that were excavated during the Tahoe epoch were reoccupied and rejuvenated during the Tioga epoch. In such cases the

FIGURE 13.—*A granite Roche Moutonnée of the Tahoe Stage*

The view, taken in Leavitt Meadow, shows how weathering and erosion have changed its original smooth, rounded contour to one that is more angular and ragged.

forms left by the earlier glaciers have been largely effaced by their successors. Many of the old cirques, however, were not occupied by more recent glaciers, and hence their contours are now subdued by weathering, so that they lack the barren, ragged aspect of the younger ones. Some have been gashed by ravines. Talus and even soil have formed in others to such an extent that the plucked rock surfaces are much obscured. The accumulation of soil has permitted the growth of forest and shrubbery which further help to conceal the original glacial features and soften their appearance. Although in some cases it is uncertain whether a particular cirque dates from the Tahoe epoch, there is nevertheless a prevailing difference in aspect which becomes familiar to one who studies

and compares a series of these glaciated valleys. Above elevations of 6,000–8,000 feet the Sierra Nevada is characterized by vast areas of comparatively bare granite, upon which so little forest grows that the rock stands out gray or white. Some of this dates from the latest or Tioga age, but by far the greatest expanse is a legacy of the Tahoe age, when the heads of the great glaciers on the western slope were largely confluent across the divides.

FIGURE 14.—*Glaciated Outcrop of Granite of the Tahoe Stage*

Weathering has destroyed the original striated surface, except on the dense resistant xenoliths which now stand out about 1 inch in relief. Near Blood's ranch, Big Trees quadrangle.

In the bottoms of the glacial troughs old roches moutonnées are easily recognizable by their rounded forms, but when they are examined for glacial polish and striations it is found that such surfaces have almost entirely disappeared. In the areas where granite is the bed rock, one finds only scattered traces of the original surface, except beneath a protective covering of earth or sod. Here and there, however, striæ may be found on quartz or aplite veins that have resisted weathering. Many of these protrude several inches from the general surface, thus affording a measure of the depth to which the granite has wasted away. Where dense resistant rocks such as hornfels or quartzite occur, large areas of glaciated surface may still be found, although usually they are dull and much shattered by the action of fire and frost.

MORAINES ALONG THE EAST BASE OF THE SIERRA NEVADA SOUTHWEST OF MONO LAKE

In the center of the view a large smooth lateral moraine of the Tahoe stage extends out from Bloody Canyon. The scarcity of boulders and the absence of a terminal moraine are typical. To the right, in front of Mount Dana, is a maturely eroded mass of till of the Sherwin stage resting upon granite; the white line marks the contact. The Tioga stage moraines of Bloody Canyon are scarcely visible.

The moraines of the Tahoe stage are commonly so large and massive that they overshadow the rather diminutive moraines of the Tioga stage. Old lateral moraines standing 500 to 1,000 feet high are not uncommon, as at Fallen Leaf Lake and west of Bridgeport. In most cases the terminal part of the moraine has been largely removed by the axial stream. The latter has generally reached grade and developed a flood plain of notable width, but its tributaries, most of which are short intermittent streams, have done little more than cut notches in the lateral moraines, leaving the isolated sections still intact. At the mouth of Laurel Canyon, in the Mammoth Basin, the huge glacial embankment which stands nearly 1,300 feet above the plain has been breached in the middle and the opening is now occupied by a small moraine lobe belonging to the Tioga stage.

Deep ravines 2 miles long have been eroded back into the large moraines of the Tahoe stage southwest of Bishop and southeast of Mammoth.[5]

The original knob-and-kettle features of the moraines are still preserved here and there, but around the margins the growth of ravines has locally obscured them.

Two imposing moraine loops were built on the west side of the Mono Lake basin by large glaciers of the Tahoe age. Subsequently, erosion destroyed most of the terminal part and left only the lateral ridges. When the lake afterward rose to its maximum height, its waves carved well-defined terraces on the ends of these two sets of moraines (Leevining and Lundy canyons). This rise of the lake was probably brought about by the more favorable climate during the Tioga glacial epoch, but at that time the glaciers were shorter and did not reach the shore of the lake.

Nearly all of the glacial lakes of the Tahoe epoch have disappeared. A few of them not entered by streams are still represented by marshy ponds. The majority have been converted into delta plains, now meadows, through which the axial streams meander. Some of these lake plains have since been intrenched by the streams, as the encircling moraines were cleared away.

Boulders are much less common on the Tahoe than on the younger moraines; the average of many careful estimates is about 70 boulders (more than 1 foot in diameter) per acre. Seldom are there more than 200 per acre over any considerable area. This may be due partly to the disappearance of boulders by decay, but in the writer's opinion is probably due to the accumulation of wind-blown dust, concealing most of the

[5] Mount Morrison Quadrangle, U. S. Geol. Survey.

FIGURE 15.—*A filled Lake of the Tahoe Stage*

The locality is Leavitt Meadow in West Walker Canyon. Other glacial features shown in this view are a fresh cirque of the Tioga stage (*A*), old cirques of the Tahoe stage now partly filled with talus (*B*), and remnants of a very old (Sherwin) lateral moraine (*C*).

smaller or partly embedded boulders. Fresh road cuts near June Lake show this to be the fact at least in that locality.

Nearly all of the granitic boulders are considerably discolored and decayed, and some of them are decidedly rotten. The granite weathering ratio [6] on the Tahoe stage till is commonly about 20–70–10. Only very rarely do any of the "granites" retain glacial striæ unless the boulders have been buried, but many of the resistant siliceous rocks still show them distinctly.

In fresh road cuts the Tahoe till generally has a light buff color which is rather characteristic in contrast with the distinctly ash-gray color of the youngest moraines. Commonly a tawny brown oxidized zone extends downward 2–3 feet.

In the Mono Lake and Mammoth basins the moraines of the Tahoe stage are distinguished by a rather thick coating (1 to 10 inches) of rhyolitic ash and pumice lapilli that appears to have been ejected by the neighboring Mono volcanoes. Very little such material is to be found on the younger moraines of the Tioga stage except locally near June Lake.

Northeast of June Lake five or more small cones of red cinders and bombs rise in the midst of the Tahoe stage moraine. Russell (1889, p. 345) regarded them as separate volcanoes built upon the moraine by eruptions penetrating from below at each point. Recently, however, Mayo [7] has found good evidence that the cones are spatter cones built upon a rather broad lava flow which had been poured out over the moraine after the Tahoe age but before the Tioga age. It is a very regrettable fact that all but two of these interesting little cinder cones have recently been almost destroyed by the local roadmakers in search of road metal. As described by Russell (1889, pp. 345 and 376), one of the large viscous obsidian flows poured down over the edge of this same Tahoe moraine from the Mono volcanoes on the east side.

The moraines of the Tahoe stage were much more extensive than those of the Tioga stage and they terminated at elevations averaging about 500 feet lower. West of Truckee the earlier glacier extended down the valley to about 5,800 feet and, as Knopf (1918) has reported, the Big Pine Glacier of the same age descended to about 4,700 feet above sealevel. On

[6] This is a percentage comparison of boulders of three classes: (*a*) those that are substantially unweathered, (*b*) those which are notably weathered externally but are still comparatively sound, and (*c*) those which are more or less completely rotted. The comparison is made exclusively on the common types of rather coarse-grained granitic rock. See page 877.

[7] Evans B. Mayo, personal communication

of the Tioga stage (*A*), old cirques of the Tahoe stage now partly filled with talus (*B*), and remnants of a very old (Sher-
win) lateral moraine (*C*).

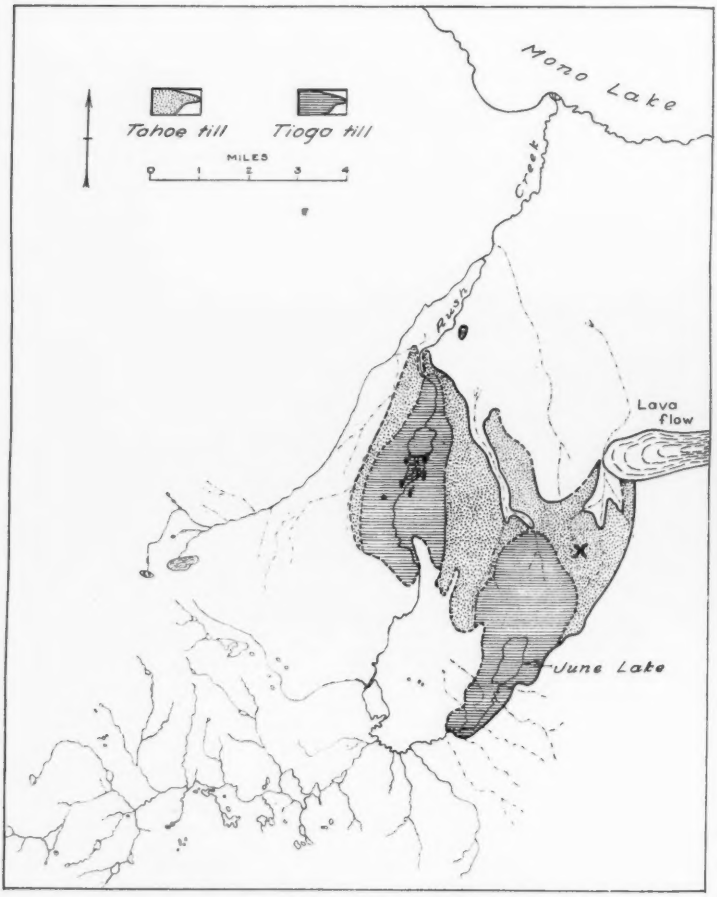

FIGURE 16.—*Moraines near June Lake in the Mono Basin*

The greater effects of stream erosion on the Tahoe moraines, as compared with the Tioga moraines, is well shown. The obsidian flow from the Mono volcanoes on the east covered a bit of the older lateral moraine. The basic flow and spatter cones are in the area marked X.

the western slope of the Sierra Nevada the Merced Glacier terminated near Bridal Veil Falls at an elevation of 3,900 feet.

In spite of the degree to which they have suffered from erosion, it is still possible to map these moraines in considerable detail and to trace them to

the cirques from which the glaciers came. The moraines were deposited within the major valleys of the region after the latter had been excavated to their present general dimensions. Nevertheless, the principal streams have cut through the frontal moraines and in some cases from 20 to 125 feet down into the underlying rock. Where the rock is much jointed, and the gradients steep, one finds the deepest postglacial trenches. An excellent example is the gorge 75–100 feet deep in jointed rhyolite about 1 mile east of Webber Lake (Truckee Quadrangle). Another defile, that has been cut 35 feet down into moderately jointed granite, may be seen along the

FIGURE 17.—*High morainal Embankment*

This embankment is at the mouth of Laurel Canyon, near Mammoth. Most of the mass is of Tahoe age. Many small ravines have been eroded in its slopes. The breach in the rim is now partly filled by a smaller moraine lobe (X) of the Tioga stage. Fresh cirques appear in the rear.

Sonora Pass highway about 3.6 miles east of the pass. There is a similar trench in the bottom of the canyon 14 miles west of the pass. One of the deepest gorges of this kind is situated just west of Pickle Meadow (Dardanelles Quadrangle), where the west fork of Walker River has cut 125 to 150 feet into andesitic pyroclastics and flows veneered with till of the Tahoe stage.

Glacial terraces pertaining to the Tahoe stage have been studied in the Truckee Valley on the eastern slope and in the Merced Valley on the west. At the town of Truckee the remnants of the valley train coalesce with the Tahoe stage moraine and extend northeastward down the river nearly 40 miles to the city of Reno. Beyond that they disappear and it has not been found possible to trace them farther. The Tahoe terraces, of which there are two distinct levels, now stand 75 and 60 feet above the river just below Truckee, 75 and 60 feet at Verdi, and 60 feet on the west edge of Reno. The gravel contains many boulders 1 to 3 feet in diameter and a

FIGURE 18.—*Gorge eroded through a Moraine*

This gorge has been eroded through the moraine and down into the underlying lava to a depth of 90 feet since the Tahoe age. The locality is east of Webber Lake, Little Truckee River.

few as much as 6 feet. They are notably decayed, but few are rotten to their cores. In color the deposits are buff near the surface but ash gray below. Similar terraces less favorably developed were observed east of Webber Lake, on the Carson River, and on the West Walker River.

Sherwin stage.—There is a considerable body of evidence suggesting a glacial stage intermediate between the Sherwin and the Tahoe stages, but

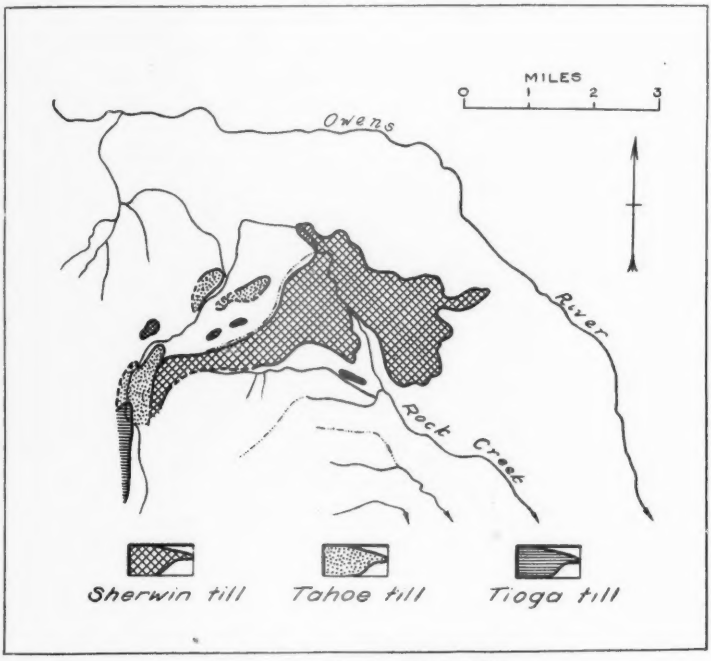

FIGURE 19.—*Sherwin Hill Locality*

The map shows the relations of the moraines of the three youngest stages. The deep transverse ravine of Rock Creek is clearly indicated. See also Figure 20.

the writer prefers to leave the discussion of this question until subsequent field studies shall have furnished a surer basis for interpretation.

One of the best localities for the recognition of the Sherwin (or second) glacial stage is the area north of Sherwin Hill[8] northwest of Bishop. Other good opportunities may be found on mountain spurs southwest of

[8] Mount Morrison Quadrangle, U. S. Geol. Survey, topographic map of the United States.

Mono Lake, on the Mono-Virginia Creek divide south of Bridgeport and especially around the forks of West Walker River.

In general, the original glacial topographic features of this stage have been almost entirely destroyed by advancing stream erosion. No lakes, cirques, or roches moutonnées of this age have been recognized and only occasional remnants of morainic forms. The terminal moraines are entirely gone, but occasional traces of lateral moraines are suggested by sections of old bouldery terraces along the mountain sides. In general, the till has been eroded to the stage of maturity and the main streams have cut deeply into the underlying rocks. North of Sherwin Hill, Rock Creek has incised its valley 600 feet into the granite below the till. Near the forks of West Walker River [9] remnants of the Sherwin till lie upon rock buttresses 800–1,000 feet above the river. Relations of this sort are governed by the physiographic history and lithology of the various localities, and hence uniformity is not to be expected.

The Sherwin stage is now clearly represented by little except large bodies of unmistakable till. Upon these patches of glacial drift the boulders of igneous rock are all much weathered, most of them notably exfoliated and many quite rotten. Only the siliceous rocks retain striæ. The surviving boulders are sparsely distributed over a smooth grassy soil-clad slope, but fresh excavations show that they are abundant only a few feet below the surface. This indicates that the actual decay of the boulders has had more to do with their disappearance than the burial of them by windblown and rain-washed soil. Decay has penetrated deeply into the till. Boulders 3 feet thick have been readily cut through by the jaws of the steam shovels at depths of at least 20 feet below the surface. Nevertheless, the writer has found little to indicate that a definite soil profile has been developed here, as described by Kay (1929), Leighton, McClintock (1930), and others regarding the old tills of the Iowa-Illinois region. No doubt the cold semiarid climate is unfavorable to thorough chemical decomposition.

That windblown material has covered the Sherwin till deeply in some places is indicated by conditions between June Lake and Mammoth. The whole area is buried in ash and pumice lapilli to depths of 3 to 10 feet or more, but occasional road cuts and ravines have discovered beneath this volcanic deposit erratic boulders of granite and metamorphic rocks 5 to 15 feet in diameter traceable to the Sierra Nevada some miles farther west. If glacial, they are probably of Sherwin age.

[9] Bridgeport Quadrangle, U. S. Geol. Survey.

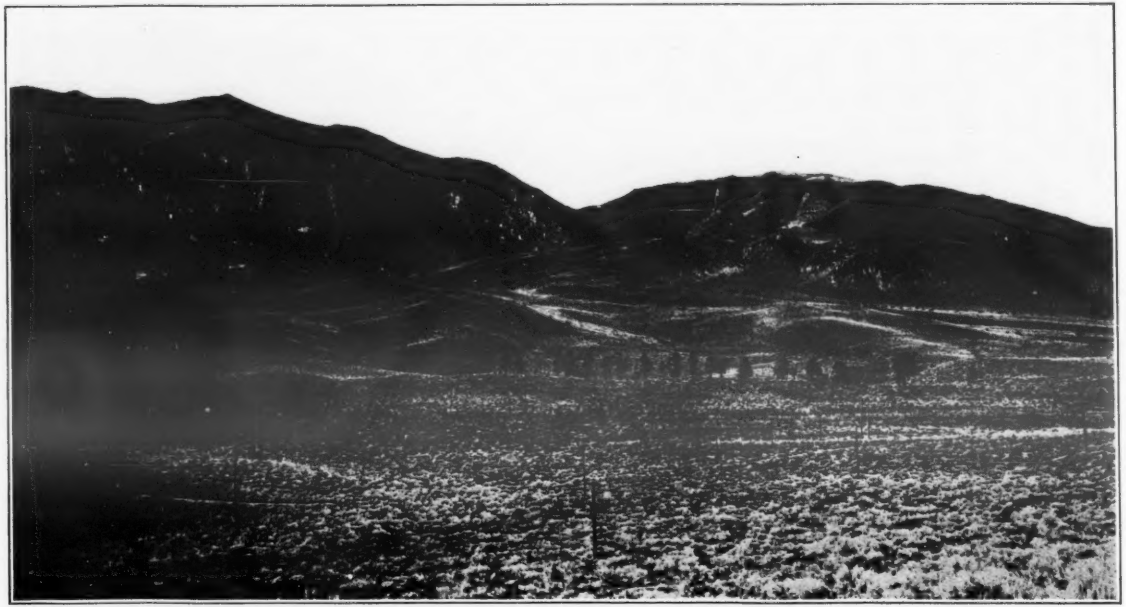

FIGURE 20.—*Maturely eroded Mass of Till of the Sherwin Stage*

The locality is along the base of the Sierra Nevada east of Rock Creek. The original morainic features have been wholly obliterated. The deep postglacial ravine of Rock Creek crosses the center of the view just beyond the line of pine trees. See Figure 22 for cross-section of this locality.

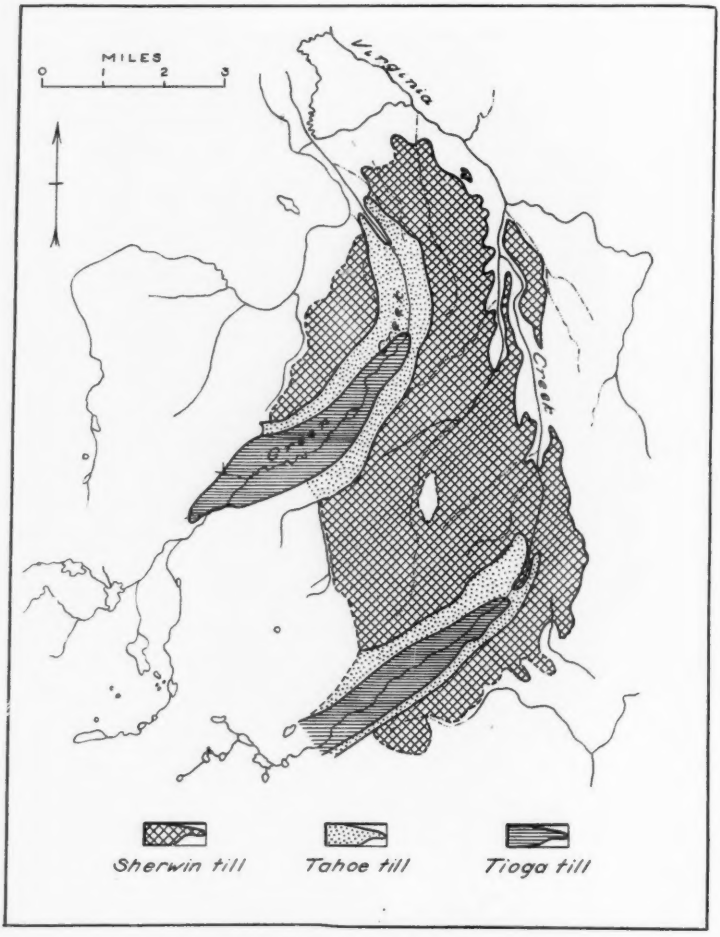

FIGURE 21.—*Virginia Creek Moraine System*

The original outline of the Sherwin moraines has been obliterated by the advance of erosion. South of Bridgeport.

Boulders are much less frequent on the surface of the Sherwin till than on either of the younger sets of moraines. In many places the number is less than one per acre and in but few does it exceed 100 per acre; the average is less than 20. They are generally more abundant on

ridge tops and on the edges of terraces where the till is exposed to excessive deflation and rain erosion. They are correspondingly rare in depressions, where slope wash tends to deposit around them the sediment from adjacent hillocks.

It would be difficult to recognize the glacial origin of the Sherwin till if it were not for the excellent exposures in fresh road excavations. There the wholly unstratified nature of the deposits is clearly revealed and one may readily find many stones scratched and facetted in the characteristic glacial manner.

It is no longer possible to map the moraines of the Sherwin epoch fully, although locally one may trace their original outlines rather indefinitely. Generally, it is difficult to detect any distinct margin around one of the patches of old till, and one may often find beyond the till itself scattered boulders, foreign to the locality, which strongly suggest that they are the sole remnants of a thin layer of till of which all else has wasted away.

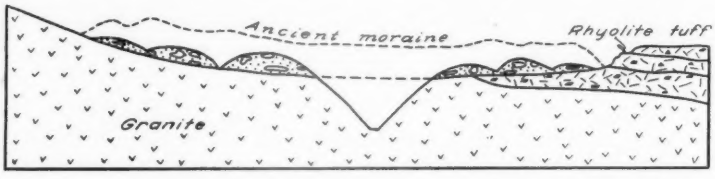

FIGURE 22.—*Transverse Section of Rock Creek Canyon North of Sherwin Hill*
Showing the position of existing remnants of the Sherwin till and the probable original surface of the moraine.

The present distribution of their remnants indicates that the Sherwin moraines were formerly much more extensive than those of either the Tahoe or the Tioga epoch. It also shows plainly that the major topographic features of the district have been notably changed since the till was deposited. That a relatively large part of the morainic tongues has been wasted away by erosion and deflation is indicated not only by the frayed and patchy distribution of the deposits but also by the ragged salient outcrops of solid rock that protrude through the till in many places. As such rocky knolls are the very kind of feature that is readily destroyed by glaciers, one may safely conclude that they have weathered out into relief upon the sites of smoother rounded hills of rock that had been duly shaped by the ice. Good examples may be seen near Dog Creek in the region south of Bridgeport. (See figure 6.)

Glacio-fluvial terraces of Sherwin age beyond the area of glaciation have not been surely identified, although it seems possible that they are pres-

ent along Truckee River southwest of Reno. The terraces in question stand 180 feet above the river. Fresh road cuts show that they are underlain by gravel varying in thickness from 30 feet to more than 150 feet and containing boulders as much as 15 feet in diameter, derived from the head of the Donner Lake valley. The deposits are not mudflow materials, but are well sorted and stratified sand and gravel such as are normally deposited by rivers. In contrast to the river terrace gravels of Tioga and Tahoe ages, these gravels are somewhat rusty in color, as though they had been subjected to a climate warmer and moister than

FIGURE 23.—*Typical isolated granitic Boulder on the Sherwin Till, Rock Creek Plateau*

The rock is cavernous and crumbly (rule 6 inches long indicates size of boulder).

today. Unfortunately these terraces have not been traced into connection with any body of Sherwin till. Possibly they belong to a glacial stage intermediate between Sherwin and Tahoe.

In spite of the fact that the Sherwin glaciation was much more extensive than either of the subsequent ones, the topographic changes due to erosion and perhaps diastrophism since its day are so large that the lower edges of the old till remnants now stand at an average elevation of more than 7,100 feet.

FIGURE 24.—*Mount McGee as seen from the North*

In the foreground the ravine-scarred terminal moraine of the Tahoe stage rises to a height of 400 feet. A lobe of similar age occupies the tributary canyon at (*B*). On the top of the ridge (*AA*) the isolated bodies of the oldest till (?) of the McGee stage stand at elevations of 3,000 to 3,300 above the plain. Mount Morrison is at the extreme right.

McGee stage.—The earliest of the four stages now recognized in the Sierra Nevada is represented only by isolated bodies of boulder earth, the original relations of which are now problematic. On the high ridge west of McGee Peak [10] several thick patches of a deposit strongly resembling till and consisting largely of granite débris rest upon a foundation of Paleozoic slate and marble.

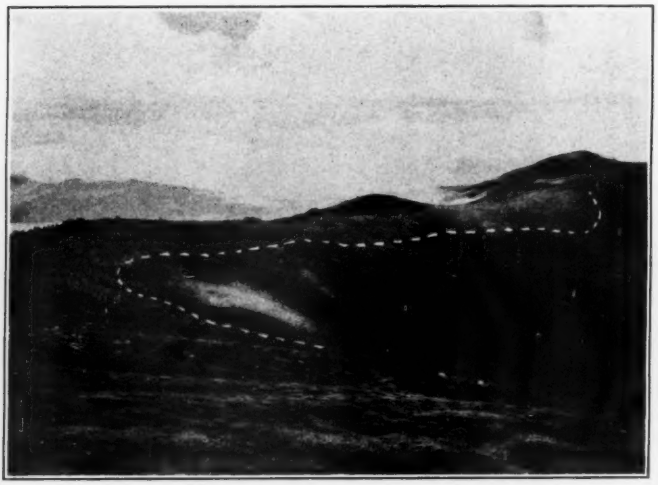

FIGURE 25.—*Crest of high Ridge Southwest of Mount McGee*

Showing the largest patch of ancient till (?) resting on black slate. The white line marks the contact. Camera faced north.

Regarding these deposits it is important to inquire whether they are surely of glacial origin and also to determine their geologic age.

Since the material consists largely of granitic rock and yet rests upon metamorphic sedimentaries it must be a transported deposit. Hence its boulders can not be due to exfoliation and decay in place. It is estimated that 10 to 30 per cent of the material consists of boulders. Many of the blocks exceed 10 feet, some 15, and a few even 20 feet in length. The dimensions of the largest are 28 by 16 by 9 feet. Transported material of these characteristics seems possible only in the deposits of mudflows, landslides, or glaciers. To differentiate these three, under the circum-

[10] Mount Morrison Quadrangle, U. S. Geol. Survey. Topographic map of the United States. See also geologic map of the district by E. B. Mayo, soon to be published by the California State Division of Mines.

stances of this case, is difficult because most of the essential criteria are lacking. Topographic forms and physiographic relations have been wholly destroyed by erosion. There are no large excavations available, and a search of the deposit during two visits to the mountain did not yield any boulders that show definite glacial scratches, although a few showed forms and vague grooves that are suggestive of glacial action. A single striated cobble of quartz slate was later found by Mr. Matthes in the course of a visit to the crest of Mount McGee. The scarcity of striated stones may be explained by several considerations. About 95 per cent

FIGURE 26.—*Detail of eroded Surface of the ancient Till (?) on Mount McGee*

Showing dark xenoliths weathered out in relief on the granitic boulders. Photograph by E. B. Mayo.

of the boulders consist of granite and a little marble—rocks that are so susceptible to decay that none of them show any trace of their original surfaces. Most of them are deeply cavernous and crumbling. The remaining quartzite, hornfels, and slate fragments should retain any markings they may have had, but it is significant that, on descending over the moraine of the Tahoe stage, where such dense rocks form more than two-thirds of the boulders, the writer found only six striated fragments, all of which were rather obscure. It is common observation that glaciated stones are much less plentiful upon alpine moraines than in ice-sheet till. For these reasons the scarcity of striated stones in the McGee tilloid [11] need not be given undue weight.

[11] Meaning a till-like deposit of doubtful origin.

It is perhaps significant that the McGee deposits can be proved to have been transported as much as 3½ miles from the parent outcrops. This is rather a long distance for landslides, but not for mudflows and glaciers. Their position close to the main divide of the Sierra Nevada, where glaciers have reigned in successive epochs, reinforces the writer's inference that they too are of glacial origin, but the opinion is not established beyond reasonable doubt.

The great age of the McGee tilloid is indicated by its position and its relations to physiographic history.

The original moraine (?) has been reduced by erosion to a few small patches that represent only a minute fraction of the whole. In that respect it offers a marked contrast to even the deeply eroded Sherwin till.

It is also significant that these remnants now lie on the tops of divides, in situations where neither mudflown or glacier could possibly emplace them, with topographic conditions as they are now. If at the time these deposits were formed, the eastern front of the Sierra Nevada had stood 3,500 feet above the plain, as it now does, there must inevitably have been valleys of appropriate depth incised in that front. Any glaciers or mudflows of that age must have been diverted down such canyons. The distribution of rock outcrops in the vicinity is such that the old tilloid, consisting almost entirely of granitic débris, could have been derived only from the large outcrop of granite near the head of McGee Creek, for all the adjacent mountains consist of metamorphic sedimentary formations. Under existing conditions a glacier from that locality would have to climb a steep mountainside 2,000 feet high to reach the present site of the ancient tilloid remnants. From these facts it is concluded that the deposits on Mount McGee antedate the present eastern front of the range with its deep canyons. It is reasonable to suppose that while such great topographic changes were being brought about, the mountain peaks of that day were largely demolished and have been succeeded by the others that now adorn the landscape.

Most other localities where the existence of till belonging to the McGee stage is strongly suspected are less satisfactory for study. At such places as Minaret Pass (northwest of Mammoth) and near Ebbitts Pass, large erratic boulders of hornfels and granite, as much as 22 feet long, have been found on the level beds of andesite that form the crest of the main Sierra Nevada divide, in situations which indicate that they must have been emplaced at a time when the topography was entirely different from that of today.

One of the most important areas for the study of ancient glacial deposits is around the forks of West Walker River, northwest of Bridgeport. The moraines of the Tahoe stage are well developed and typical. Above and beyond them are copious deposits of till and stratified drift of the Sherwin stage, greatly eroded and somewhat indefinite of outline, but unmistakable. The Sherwin moraine remnants rise to about 7,800 feet elevation near the forks. Above and beyond them, to the north and east, the maturely dissected slopes of bedded andesitic flows and

FIGURE 27.—*One of the isolated granite Erratics*

These erratics, on the andesitic crags at the summit of a mountain southeast of West Walker Canyon, are suspected of belonging to the McGee stage. Position of the canyon 2,300 feet deep shown by arrows.

pyroclastics are strewn rather sparingly with erratic boulders up to elevations of about 8,700 feet and probably higher. The boulders comprise epidotic hornfels and granitic rocks, including some of the giant porphyry (Cathedral Peak granite) of the Sierra Nevada crest. Some of these rocks can be traced to exposures at least 15 miles up the valley to the southwest. The blocks are of all sizes up to 20 feet in length. The granites are deeply decayed, exfoliate, and cavernous. It is difficult to understand how such large blocks could be transported on a gradient of only 50–100 feet per mile for 15 miles or more except by the action of a

large glacier. The conditions of this case seem to be too severe for the mudflow hypothesis.

That the deposits are very old is shown by their position far above and beyond the Sherwin moraine remnants, by the fact that the ancient tilloid has wasted away, leaving only scattered boulders, and especially by the fact that West Walker River has since cut a V-shaped canyon more than 2,000 feet deep below the base of the ancient glacial deposit. A comparison of the weathering of the oldest boulder deposits of this area with those on Mount McGee also suggests that they are of similar age.

In 1906 Willard D. Johnson found a bouldery deposit on the side of Rickey Peak [12] at an altitude of about 9,700 feet, but he was not sure that it was of glacial origin. He also noted other boulder deposits at high levels at various points farther north in the West Walker River drainage area, and suspected that they belong to a glacial stage much older than the certainly recognized (Sherwin) till at lower levels.

Other ancient boulder deposits of this stage will doubtless be found upon high spurs along the Sierra Nevada, but the land surface of that age has been so largely consumed by the growth of deep canyon systems that there can be little hope of finding many or large remnants of this drift.

Correlation

Foreword

For purposes of correlating the glacial phenomena on the eastern side of the Sierra Nevada with those in certain parts of the western United States the writer has examined several districts in California, Nevada, Utah, and Wyoming, applying there the same criteria and comparing his results with the findings already published by Atwood, Alden, Matthes, and others. He has previously studied in some detail the glacial phenomena of the Bighorn (1903), Wind River, Gros Ventre, Teton (1915), and Wasatch Mountains, but most of the information thus derived has never been published.

Western slope of the Sierra Nevada

The climate of the western slope is moist, the forest thick, and the rate of rock decay doubtless more rapid than on the east side. These differences introduce some factors that the student should keep in mind while comparing the glacial features of the two slopes. In general, the forest conceals distinctive glacial topography and in other ways hinders the study of physiographic history on the western slope.

[12] Bridgeport map.

In September, 1930, the writer had a field conference with Mr. Matthes in the Yosemite Valley, and at that time certain correlations and interpretations were agreed upon. These were later supplemented by a reexamination by the writer in March, 1931. As a result, the following are offered as being the most reasonable tentative conclusions, but they are solely the writer's and are accepted only in part by Mr. Matthes.

The Tioga stage is evidenced by the freshly glaciated rock slopes in Tenaya Valley above the gorge and in Merced Valley above the Nevada Falls, by the unfilled lakes such as Tenaya and Merced Lakes, by the lack of notable intrenchment of the granite by the creeks, and by the fresh condition of the glacial boulders. At that time neither the Tenaya nor the Merced glaciers descended into the Yosemite Valley proper and only small glaciers existed in the valleys of such tributaries as Yosemite Creek and Illilouette Creek. Moraines of this stage are small and inconspicuous. The writer does not yet know which of them marks the farthest advance of the ice of the Tioga age.

The identification of the Tahoe stage has been less confidently made in the Yosemite region than in almost any other part of the range and the writer is still unable to reconcile some of the conflicts in testimony of the observed facts. However, the weight of evidence indicates that the glacier of that age advanced into Yosemite Valley and built the moraines below El Capitan and Bridal Veil Falls. Like the Tahoe moraines of other valleys in the Sierra Nevada, these occupy the bottom of the canyon and are the largest and most advanced of the moraines so situated. The till is somewhat buff in color, most of its constituents are notably weathered and some of the boulders are crumbly. The large lake impounded by the moraine loop has not only been completely filled by the delta, but the river has since consumed most of the lake plain in excavating a flood plain about 15 feet lower. The rocks along the canyon wall are rather crumbly and retain the original glacial surface in only a few places. The altitude of the terminal moraine (3,950 feet above sealevel) corresponds closely with that of other Tahoe stage moraines [13] on the western slope and is much lower than that of any Tioga stage moraine known in the entire range. During the Tahoe stage, glaciers in the Yosemite Creek, Illilouette, and Snow Creek Valleys failed to reach the Merced Canyon. Below El Portal there are remnants of a gravel valley train resting upon rock terraces about 30 feet above the Merced River. The top of this valley train once stood about 55 feet above the river, but it is now generally covered by talus and mudflow débris from the slopes above and is exposed

[13] Yuba River 4,000 feet, and Kings River 4,150 feet.

only in the road cuts and canyon walls. The decay and color of the pebbles and the depth of trenching suggest that this is the valley train of the Tahoe stage. It resembles that east of Truckee.

Till of much older aspect, almost wholly devoid of glacial topography, appears in isolated but numerous patches here and there in the Yosemite region. This is the older till (El Portal stage) of Matthes (1931). Among the best places to study it are south of Glacier Point, at Old Fort Monroe, in Big Meadow, and especially north of Gentry checking station. In all cases it lies on slopes or shoulders 1,000–3,500 feet above the present river. The till is decayed to depths of over 10 feet and is covered with an orange-buff soil that conceals nearly all of the boulders. Even in fresh road excavations it is very rare to find distinctly striated stones. Where the subjacent rock surface has been recently exposed by removal of the till, glaciated surfaces have been observed at only one or two places, because the bed rock is itself deeply decayed. Many of the boulders in this till are characterized by a decided reddening of the decayed exteriors—a trait not found in either of the two younger tills, but common on Sherwin till elsewhere in the range. The granite weathering ratio is about 0–15–85 and the frequency about one per acre. The western limit of the old rusty (El Portal) till has never been ascertained. It is now agreed between the writer and Mr. Matthes that the supposed moraine in the valley bottom at El Portal is really a local deposit of mudflow or landslide material. The writer suspects that the ancient glacier formerly extended a few miles west of El Portal and that the cutting of the inner canyon and its deep tributary ravines has destroyed all trace of the terminal moraine and valley-train terraces that once extended west of it. In general, the various characteristics of the El Portal till indicate that it belongs to the Sherwin stage.

Evidence of the McGee stage on the western slope of the Sierra Nevada is scanty and unconvincing. On the north slope of Sentinel Dome and in other similar positions there are large isolated boulders regarded by Matthes as glacial erratics left by the wastage of a moraine much older than the (Sherwin?) till remnants below it near Glacier Point. Since Matthes and Calkins seem to have proved that the Sentinel Dome blocks were transported hundreds of feet up the adjacent slope, it seems probable that they are glacial erratics. The writer is not convinced, however, that they are older than the ancient till (Sherwin?) that covers the slope below. Thin till on a mountainside may easily be washed away, leaving only a few resistant blocks. In fact, the boulders may originally have

been isolated on the rock surface, as were the thousands which now adorn the most recent "glacial gardens" of the Tenaya Lake basin.

In summary, it appears to the writer that (*a*) the Wisconsin stage of Matthes includes both the Tioga and the Tahoe stages, (*b*) the El Portal stage is the same as the Sherwin, (*c*) the Glacier Point stage is probably not distinct from the latter, and (*d*) there is, as yet, insufficient evidence of the McGee stage in the Merced River basin.

Along Yuba River [14] (also the Southern Pacific Railroad) the three youngest glacial stages were found by the writer to be consistently developed. The Tioga stage is represented by weak cirques, a nearly filled marshy lake at Soda Springs Station, and some very low moraine loops at an altitude of 6,500 feet a few miles farther west. The glacier was only about 200 feet thick and 5 miles long.

The Tahoe stage glacier was much larger and more vigorous. To this stage are ascribed most of the great expanses of barren granite in the névé region of the old glacier. The ice descended the Yuba Valley to Emigrant Gap and projected a lobe on through Bear Valley to an altitude of 4,000 feet, thus corresponding closely with that in the Yosemite Valley. The glacier was 2 miles broad in its central portion and over 24 miles long. At Cisco it was more than 600 feet thick, and it exceeded 1,000 feet in depth at Emigrant Gap where its south lateral moraine now forms the crest of the divide. The till on this moraine has a G. W. R. of 15–77–8 and a boulder frequency of about 80 per acre, and the soil is buff. The moraine has not been badly marred by erosion, but a large lake that once existed north of Emigrant Gap has been filled and converted into a level meadow.

Till corresponding to the Sherwin stage was found in road cuts and along the railroad 2 miles northwest and 1 mile northeast of Blue Canyon Station, several hundred feet above the creeks. Its glacial origin is inferred from its unsorted structure and from the great size of the erratic boulders (10 to 20 feet). Striated surfaces are retained on only a few of the boulders. As in the Yosemite region, the boulders are not only well rotted, but are distinctly rusty in color. Since the topography is now maturely erosional, the geologist has only the rather infrequent excavations for a guide in mapping the till. Hence its actual distribution may never be determined. When the distribution of bedrock formations becomes more accurately known, it may be possible to distinguish more certainly between old till with erratic boulders and residual soil inclosing boulders of decay.

[14] Colfax and Truckee quadrangles, U. S. Geol. Survey. Topographic map of the United States.

Ancient till, here referred to the Sherwin stage but possibly in part of greater age, occupies ridge tops in many places between Yuba and Merced canyons. Long ago Turner, observing their advanced state of decay and greatly eroded condition, concluded that they must represent an earlier glacial epoch. The glacial phenomena of the western side of the Sierra Nevada have been closely studied in only a few localities. Many interesting facts await those who will eventually give this region the attention it merits. As yet, however, no satisfactory evidence of the McGee stage has been found anywhere on the western slope.

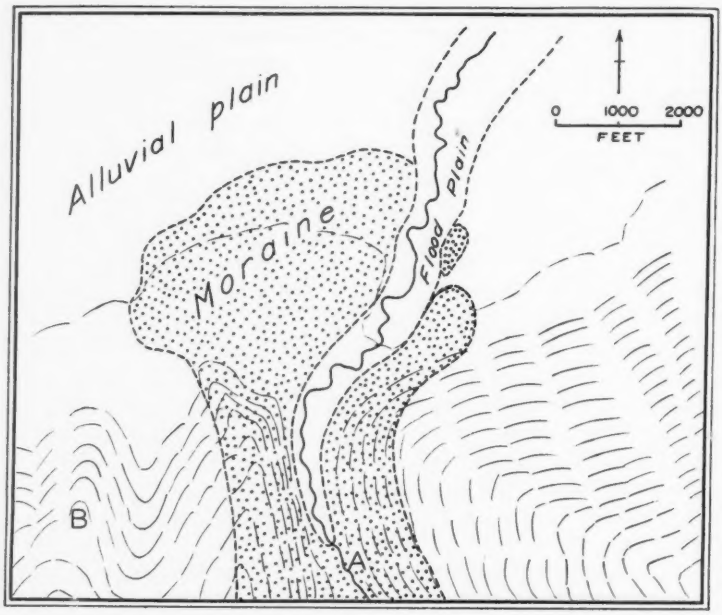

FIGURE 28.—*Location of the old Moraine (Tahoe Stage) at the Mouth of Lamoille Canyon in the Ruby Mountains of Nevada*

Possible older till (Sherwin stage) is indicated at B. The rock gorge is situated at A.

RUBY MOUNTAINS, NEVADA

The Ruby Mountains (formerly called the East Humboldt Range), southeast of Elko, Nevada, reveal ample evidence of former glaciation, as reported by Hague.[15] By applying there the methods developed on the

[15] U. S. Geol. Expl. 40th Par., vol. 2, pt. II, pp. 620-621, 1877.

dry eastern slope of the Sierra Nevada, the writer found it easy to recognize the two latest glacial stages, and he found suggestions of another, still older.

The Tioga stage is represented by small fresh moraine loops, usually inclosing clear lakes, behind which rise the wild crags of the freshly torn cirques. None of these glaciers reached the lower parts of the canyons and but few of them descended below an altitude of 8,000 feet. The moraines are very bouldery and the rocks are but little decayed. A typical and relatively accessible locality in which to study these features is at Angel Lake, southwest of Wells.

To the Tahoe stage belong the larger and more conspicuous moraines that are visible along the flanks of the range. The largest glacier of that age, about 15 miles long, issued from Lamoille Canyon and built a low bulbous moraine upon the plain. Above the mouth of the canyon the stream has cut a gorge 40 feet deep in the gneissic rock below the till and it has excavated a flood plain 500–1,000 feet wide across the terminal moraine. Several other glaciers of the same age farther south reached the base of the range, and some of the glaciers around Mount Bonpland were nearly as large. In most cases only the lateral moraines are now preserved. Even they have been distinctly marred by ravines and have been subdued to smooth rounded forms. The boulders are somewhat more decayed than is usual on moraines of this age, but the value of the comparison is diminished because the rocks observed in the Ruby Range were gneisses of sedimentary origin rather than granodiorites. Ice-worn outcrops are much broken and rarely retain even traces of the glaciated surface. Boulder frequency averages about 65 per acre and the gravel terraces beyond the moraine at Lamoille are about 50 feet high. These and the other conditions indicate the Tahoe stage.

In the rather hasty examination of the range made by the writer no sure evidence of pre-Tahoe glaciation was found. However, there is till-like bouldery material outside of and somewhat above the high southwest lateral moraine at the mouth of Lamoille Canyon. Its boulders are much weathered and sparsely distributed (3 or 4 per acre). If this material is till, its relations and condition suggest that it is a remnant of a moraine of the Sherwin stage. A careful inspection of rocky shoulders several hundred feet above the base of the range may well reveal more decisive evidence.

The Snake Range in southeast Nevada harbored several glaciers in late Pleistocene time. A bulky moraine probably of the Tahoe epoch extends from Wheeler Peak out upon the plain near the village of Baker, and the

FIGURE 29.—*Old lateral Moraines of the Tahoe Stage*

The locality is along the west slope of Lamoille Peak in the Ruby Mountains. The cirques were refreshed during the Tioga stage but the moraines of that age are scarcely discernible in the photograph.

raggedness of the cirques on the eastern slope indicates glacial action also in the Tioga age.

There are similar but weaker evidences of glaciation in the White Mountains northeast of Bishop, the Carson Range near Carson City, and the Independence Range north of Elko, in Nevada.

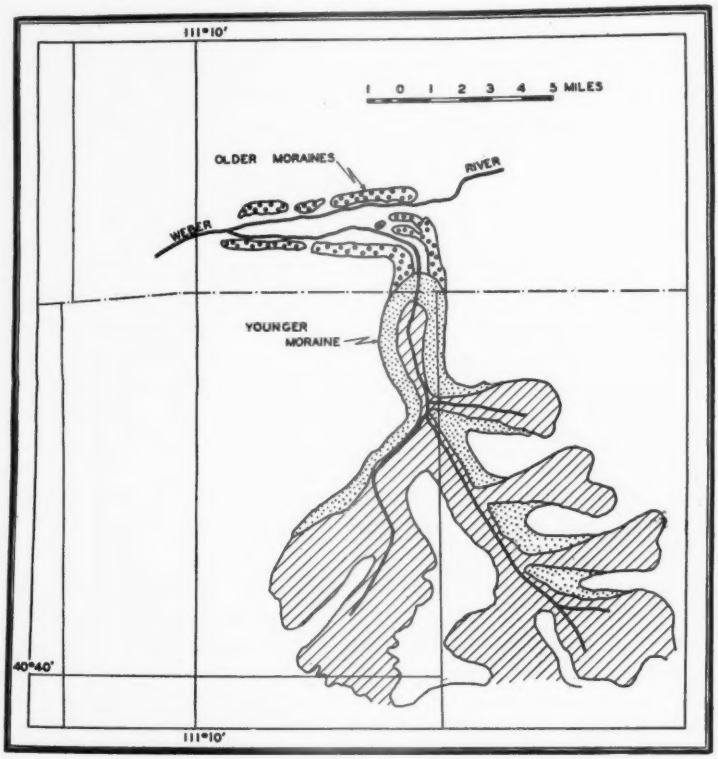

FIGURE 30.—*Moraines on Weber River in the Uinta Mountains of Utah*

The more eroded condition and greater extent of the earlier stage is well shown. (After Atwood.)

W. D. Smith (1927) has reported glaciated valleys on the west slope of Stein Mountain in southern Oregon. Much more obscure and doubtful indications of glacial action, probably of the Tahoe age, have been observed by the writer in the Sweetwater, Spring Mountain, Schell Creek, Toyabe, Humboldt, Onequi, and Beaver ranges of Nevada and Utah. Apparently none of these have been closely examined by glacialists.

WASATCH RANGE, UTAH

In his report on the glaciation of the Wasatch and Uinta ranges of northern Utah, Atwood (1909) demonstrated that two distinct episodes of glaciation may be recognized. His evidence has been reviewed in the field by several geologists, including the writer of this paper, and in general they have verified his conclusions. The moraines that were assigned by Atwood to his "later epoch" are essentially like those of the Tioga stage in the Sierra Nevada. In both places they are but little eroded, very slightly decayed, retain unfilled lakes and are of small extent. The granite weathering ratio on a frontal moraine of this age in Big Cottonwood Canyon [16] proved to be 96–4–0 and the boulder frequency 750 per acre. These are highly typical of the Tioga stage. The axial creek has not reached grade in its notch through this moraine.

The moraines of Atwood's "earlier epoch" are more extensive and much more bulky. The granite weathering ratio averages about 7–76–17 and the frequency less than 200 per acre. The granitic boulders are partly exfoliated and some of them display cavities several inches deep. Fresh exposures of the till show a yellowish and even rusty discoloration to a depth of as much as 6 feet, indicative of notable progress in the postglacial weathering processes. The creeks have rather generally cut through the moraines and 25–100 feet into the underlying rock. In nearly all cases the terminal moraines have been largely washed away by the graded axial streams, leaving only the lateral moraines. All of these conditions point directly to the Tahoe stage as recognized in California.

The moraines of both of these stages lie in the bottoms of the canyons and thus indicate that the amount of postglacial erosion has been relatively small. As yet no one has found in the Wasatch Range any patches of greatly eroded till lying upon high terraces and shoulders. As they have been reported from other districts to the north and east it seems probable that they exist also in the Wasatch region, but the dense growth of scrub-oaks and aspens effectually hides the mountain slopes and makes the search for such deposits very difficult. As roads are extended in the canyons, fresh excavations may reveal them by chance.

One of the most important questions regarding the glacial history of Utah is the relations of the glacial stages to those of Lake Bonneville. The crucial localities in which this relation can be determined are at the mouths of Little Cottonwood, Bell, and Alpine canyons, all southeast of

[16] Thirteen and a half miles by road east of the mouth of the canyon.

Salt Lake City. Only there do the lake terraces and deposits touch the moraines at the mouths of the canyons.

In his study of Lake Bonneville, Gilbert (1890) observed that there is no terminal moraine at the mouth of Little Cottonwood Canyon and that the highest wave-cut terrace of the old lake was not engraved across the ends of the lateral moraine ridges. From these facts he concluded

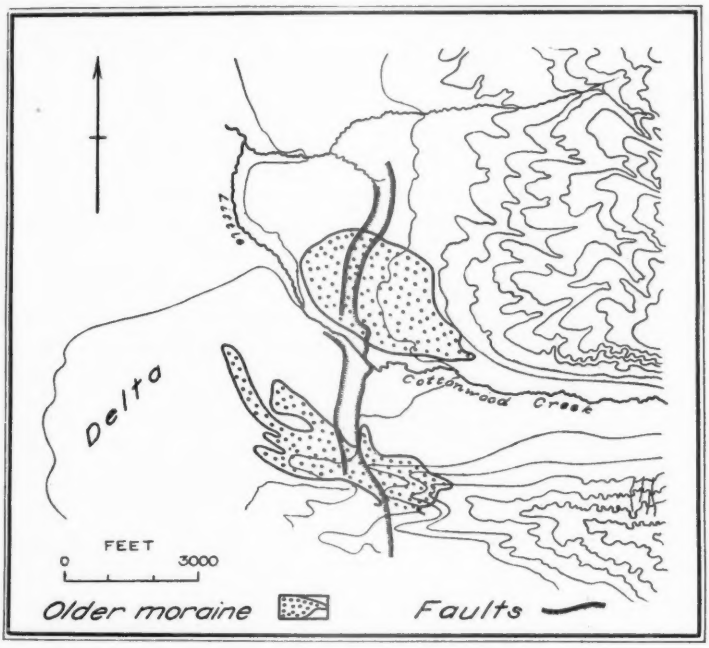

FIGURE 31.—*Map of the Mouth of Little Cottonwood Canyon, Wasatch Mountains, Utah*

Showing the relations of the moraines and terraces. (After Gilbert.)

that the glacier discharged directly into the lake and hence made no frontal moraine. On this inference the maximum rise of the lake was contemporaneous with the glaciers, and the latter belonged to the second expansion of Lake Bonneville. Later Atwood (1909) concurred in this opinion.

The present writer has carefully examined these localities. He found the delta deposits of the Bonneville substage covering the lower part of the Little Cottonwood moraines and continuing as a terrace up into the

wide breach between the gaping lateral moraines. Matters are locally complicated by postglacial faults, for which due allowance must be made. It was observed that the wave-cut terrace along the mountain front becomes steadily fainter as it approaches the great deltas and finally disappears before reaching the canyons. It is suggested that the prograding of the deltas warded off wave attack and thus prevented it from notching the ends of the moraines. This hypothesis would remove the chief objection noted by Gilbert and would permit the acceptance of the general evidence that the moraines are older than the Bonneville shore substage and that the latter is of Tioga age.

The glaciers of the Tioga age did not reach the mouths of the canyons, but river-borne detritus issuing from them entered Lake Bonneville, built deltas, and buried the ends of the longest lateral moraines. As the level of the lake went down, the original deltas were intrenched, but were enlarged in area at lower levels. Remnants of the earlier delta surfaces exist as gravel terraces that extend up the canyons.

In a cursory examination of the west end of the Uinta Mountains, the writer was able to verify Atwood's opinion that the two glacial stages there mapped by him are the same as the two in the Wasatch Range.

OTHER RANGES IN THE ROCKY MOUNTAINS

San Juan Mountains of Colorado.—In their last report on the glacial history of the San Juan region, Atwood and Mather (1931) distinguish three stages, which they name the Cerro, the Durango, and the Wisconsin.

The Cerro glaciers were of piedmont form and more extensive than the others. Only remnants of the maturely eroded till now remain and a network of canyons 500 to 2,000 feet deep has been carved subsequently. The facts strongly suggest the Sherwin stage of California.

The Durango stage is represented by large moraines inside the canyons and by gravel valley-train terraces 150–250 feet above the creeks. This indicates the Tahoe stage.

The Wisconsin moraines are lower, lie within the Durango moraines, and are connected with gravel terraces only 20–30 feet high, thus conforming closely to the Tioga stage of the Far West.

Mountains of western Wyoming.—The glacial history of the Teton, Gros Ventre, and Wind River mountains, as elaborated by the present writer (1915), includes the Buffalo, the Bull Lake, and the Pinedale stages. Although some of the criteria used in the Sierra Nevada have never been applied in this region, there is an obvious parallelism between the three stages of Wyoming and the Sherwin, Tahoe, and Tioga stages

in California. The decay of boulders, the extent and depth of postglacial stream erosion, and the relations of moraines to valleys all support this opinion. Fryxell (1930), who has recently made a detailed study of the glaciation of Jackson Hole, Wyoming, readily identified the same stages.

Mountains of western Montana.—Alden has studied the effects of Pleistocene glaciation over a large part of Montana and extended his comparisons to Wyoming, Idaho, and Washington. He concurs (1926) in the view that three stages may be distinguished and that they are essentially the same as those previously worked out in the Teton region. The Kennedy till of Montana is correlated by him with the Buffalo till of the Snake River headwaters. Two younger sets of moraines lie inside the modern canyons, but of these the earlier ones are much bulkier and more eroded than the later.

CORRELATION WITH THE STANDARD SECTION

For the United States the standard section of the Pleistocene glacial deposits is that of Iowa, Wisconsin, and Illinois. The work of many glacialists, such as T. C. Chamberlin, W J McGee, Calvin, and Leverett, culminating in recent studies by Kay, Leighton, and Alden has resulted in substantial agreement and the recognition of five distinct glacial stages: (1) the Nebraskan, (2) the Kansan, (3) the Illinoisan, (4) the Iowan, and (5) the Wisconsin. The last is divided into Early and Late Wisconsin.

Recently there has sprung up sentiment in favor of reducing the five or six stages to four by bracketing the Iowan and Wisconsin together as subdivisions of one stage. Thus Kay (1931) proposes the Eldoran epoch to include (*a*) Iowan glacial, (*b*) Peorian interglacial, and (*c*) Wisconsin glacial ages. Leighton (1931) offers a somewhat different plan to represent similar ideas; he retains the Wisconsin epoch and divides it into (*a*) Manitoban (= Iowan), (*b*) Quebecan (= Early Wisconsin), and (*c*) Hudsonian (= Late Wisconsin)—all glacial advances. The glacialists of other regions hope that these differences of usage will soon be harmonized. Meanwhile, the writer will employ the older terms in their usual meanings.

Conditions of topography, climate, and lithology change to such a degree between Wyoming and Iowa that to extend correlations across the gap would be hazardous. Fortunately, Alden,[17] who was already familiar with the glacial formations of the prairie states, has traced them more or less continuously from Iowa across Nebraska, South Dakota, and Mon-

[17] Personal communication.

tana to the Rocky Mountains, noting the gradual slight changes in character along the entire glacial margin. As a result of this research he concludes that the Pinedale stage of Wyoming is identical with the Wisconsin, and the Bull Lake stage with the Iowan. The Buffalo stage resembles the Kansan, more than either the Illinoisan or the Nebraskan, but the correlation is uncertain, since the older tills have not yet been traced across the Great Plains.

Although realizing the liability of error, especially regarding the older deposits, the writer ventures to present the following table of correlations for western United States as a tentative scheme for continuing studies. The views embodied have been reached partly in the course of field conferences with Kay and Matthes, but they are not responsible for the opinions here expressed.

The absence of stages equivalent to the Illinoisan stands out in this table as a challenge. It is reasonable to suspect that there is such a stage in the West, and indeed the writer has found some rather definite evidence of it along the eastern slope of the Sierra Nevada. The present doubt regarding its existence is probably due in part to the obliteration of the

Tentative Correlation Table of Glacial Stages in Western United States

Iowa and Illinois	Montana	Wyoming (Wind River)	Colorado (San Juan)	Utah (Wasatch)	Nevada (Ruby Mts.)	Sierra Nevada	
						East	Yosemite Matthes
Wisconsin	Wisconsin	Pinedale	Wisconsin	"Younger"	Angel Lake	Tioga	Wisconsin
Iowan	Iowan (?)	Bull Lake	Durango	"Older"	Lamoille	Tahoe	
Illinoisan	.....	.....	.....	.....	.....	—?—	
Kansan	Kennedy	Buffalo	Cerro	.....	—?—	Sherwin	El Portal
Nebraskan	.....	.....	.....	.....	.....	McGee	Glacier Pt.

phenomena by glaciers of the next later age, but largely to the inherent difficulty of making, between tills of greater age than Iowan, such nice distinctions as are possible among the younger moraines. It is therefore not unlikely that glacial deposits of Illinoisan age are present but are as yet undifferentiated from those of the typical Sherwin stage. The writer hopes to pursue this problem in the near future.

PURPOSE OF THE CORRELATIONS

The writer is interested in the glacial stages of the West, not so much for their own sakes as for their utility in reconstructing the Pleistocene history of the Cordilleran region. Many individual events in that history have been determined, but serious difficulties are encountered when the attempt is made to arrange these in consecutive historical order and still more when one tries to fit such a sequence into the general scheme of the period. Fossils are rare, and even when found they give but little comfort, because the evolutionary changes among organisms were too slow to bring about very distinct faunas within the Pleistocene period—especially in the later part.

The best and most convenient criteria at present available for working out the sequence of Pleistocene events are physiographic. For general correlations there seems to be no basis as good as that afforded by the climatic pulsations for which the Pleistocene period is noted. Such climatic variations, if due to general atmospheric or perhaps astronomic causes, must have affected all parts of the region and impressed their record upon its topographic forms and deposits. Basins held fresh lakes during the cooler epochs, but only playas or salinas in the intervening dry times. Alluvial fans grew larger in the more arid ages and were intrenched under the influence of the next cool moister régime. Such illustrations serve to indicate how the establishment of a series of climatic ages may facilitate the integration of a continuous history of the Pleistocene period in western United States.

Already tentative correlations have been extended out from the glacial area of the Sierra Nevada to the desert basins eastward as far as Death Valley and thence to the Colorado River. The great pediments and alluvial fans as well as the lake terraces and salt beds can thus be assigned to approximate geologic dates and still older features referred to them in turn.

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COLUMBIA RIVER FAULT[1]

BY EDWIN T. HODGE

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Introduction

This paper deals with the heavy Miocene lava flows, known as the Columbia River basalt, which cover a large part of Oregon and Washington; but more particularly with that part of their area along the boundary between those two States, where the basalt was in Pliocene time folded in strong anticlines, trending and pitching southwest in the Cascade Mountains, and faulted in a long, east-west trough just east of the mountains. The trough, here called Maryhill trough, was formed by a gentle down-bending of the lava so that its surface, called the Shaniko surface, slants gently northward to a strong, south-facing fault-scarp, from 3,000 to 350 feet high and about 80 miles long (Figure 1).

1. Alder Creek.....4N-22
2. Alder Ridge....4N-22
3. Antelope scarp...5-8S
4. Arlington 3N-22
5. Arlington formation N of dotted line as far as Columbia fault.
6. Artesian Coulée..4N-23
7. Big Eddy.....2N-14
8. Biggs 2N-16
9. Big Horn Canyon.4N-21
10. Blalock Canyon.3N-20
11. Canoe Ridge....5N-24
12. Cascade Mountains—all west of R. 11 E. —covered almost entirely by Cascade formation.
13. Cascade formation—west of hachured line.
14. Chapman Creek..4N-21
15. Chamberlain flat.4N-18
16. Cliffs 3N-17
17. Columbia fault and scarp — represented by solid thick line north of Columbia River.
18. Columbia River formation—underlies Cascade, Dalles, and Arlington formation and exposed in Shaniko and Goldendale surfaces.
19. Columbia scarp—see Columbia fault (No. 17).
20. Condon Lake — occupied an area a little larger than Arlington formation (No. 5).
21. Coyote 4N-25
22. Crow Butte.....5N-24
23. Dalles formation west of broken line, west to and under 13.
24. Deschutes River 2N-8S-14
25. Dufur 1S-14
26. Echo 3N-29
27. Eight Mile Creek.1N-14
28. Fifteen Mile Creek 2N-15
29. Fossil 6S-21
30. Friend 2S-12
31. Glade Creek 6N-25
32. Golgathe Butte..4N-23
33. Goldendale surface 4N-12-24
34. Goodnoe 3N-18

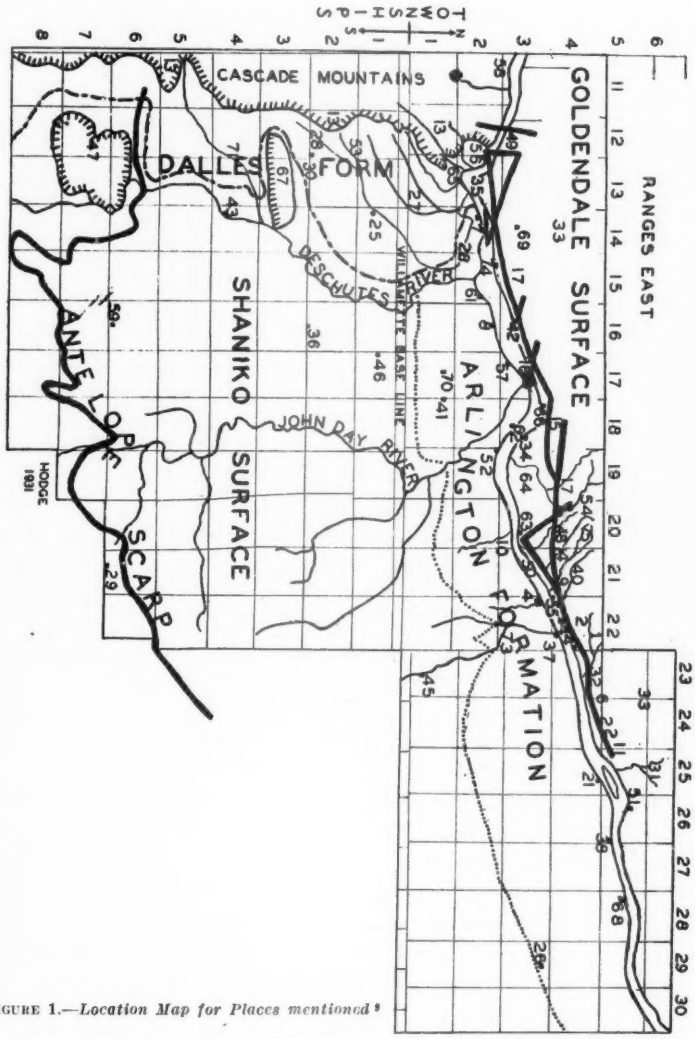

FIGURE 1.—*Location Map for Places mentioned*[2]

[2] All proper names mentioned in this paper are arranged alphabetically in the following table.

The number preceding the proper name refers to a place-number on map.

The first number following name refers to the township, north or south, as stated; the next number refers to ranges east. The township and range numbers printed on left and top margins of map will enable the reader to quickly locate the reference number.

35. Grand Dalles...2N-13
36. Grass Valley....2S-16
37. Heppner Junction 4N-22
38. Irrigon 5N-26
39. John Day River 2N-8S-19
40. Juniper Creek...4N-21
41. Klondike 1N-18
42. Maryhill 3N-16
43. Maupin 4S-14
44. Moonax 4N-22
45. Morgan 1N-23
46. Moro 1S-17
47. Mutton Mountains 7S-12
48. Old Lady Canyon.4N-20
49. Ortley Anticline..3N-12
50. Owyhee Rapids..3N-21
51. Paterson 5N-26
52. Quinton 2N-19
53. Ramsey Creek...2S-12
54. Rock Creek.....4N-19
55. Roosevelt 4N-23
56. Rowena 2N-13
57. Rufus 3N-17
58. Seven Mile Hill..2N-11
59. Shaniko 6S-16
60. Shaniko surface 2N-6S-13-30
61. Sherman 2N-15
62. Squallihook 3N-18
63. Sundale 3N-20
64. The Burn.....3N-19
65. The Dalles.....2N-13
66. Towal 3N-18
67. Tygh Ridge.....3S-13
68. Umatilla 5N-28
69. Warwick 3N-14
70. Wasco 1N-17
71. White River....4S-12
72. Williamette Base-line O-11-22
73. Willow Creek...3N-22
74. Wishram 2N-14
75. Wood Creek.....4N-20

The Pliocene Columbia River took a consequent course along the trough; thus guided, it ran beyond the entrance of the deep canyon which it has since then trenched across the anticlinal folds of the mountains and so reached a sag in the mountain belt, probably related to the southwest pitch of the anticlines. It will be shown that the Pleistocene eruptions of the 12,000-foot cone of Mount Hood, between the sag and the canyon, formed a high barrier in the sag; that a long Pleistocene lake, called Lake Condon, was then formed in the Maryhill trough east of the volcanic barrier; that the lake rose until at an altitude of 1,900 feet it overflowed a col determined by the overlap of the north-sloping lava flows (Cascades formation) and the associated detrital deposits (Dalles formation) upon the easternmost of the southwest-pitching anticlines in the mountain highlands. Thus the Pliocene Columbia River was extinguished by the volcanic barrier and replaced by Lake Condon, in which silts covered by gravels (Arlington formation) were laid down; but the river was reestablished in Pleistocene time when the lake, spilling over at the col, ran across the mountains along a course consequent on their highland surface and western slope. Part of its course was soon superposed through the Cascades and Dalles formations on the underlying basalts; and as the magnificent canyon of the present river was thus eroded through the Cascade Mountains, Lake Condon was progressively drained until the river took its place along a course consequent upon the slopes of the Arlington beds in Maryhill trough, through which it was soon superposed on the underlying basalt, in which it cut a trench of moderate depth.

To enable the reader to understand this part of the history of Columbia River it will be necessary to discuss in some detail certain features of the geology of the region that includes the major portion of the great Colum-

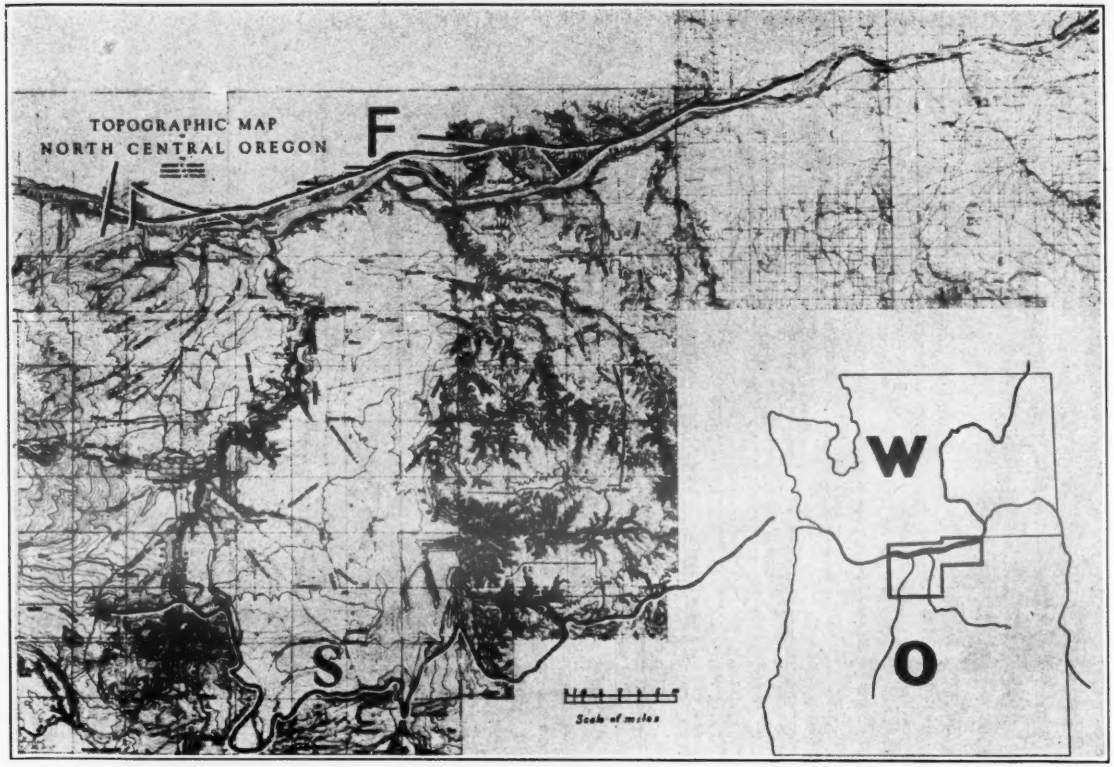

FIGURE 2.—*Topographic Map of North Central Oregon*

Area mapped is outlined by inset map of Washington (*W*) and Oregon (*O*). Line *S* is Antelope south-facing erosional scarp formed in the Columbia River basalt formation, which overlies the weaker and older John Day formation. From Antelope scarp Shaniko lava surface extends as a great north dip-slope moderately eroded to and a little beyond Columbia River, terminating at the foot of Columbia fault-scarp (*F*). The line *F* shows the main fault with its branches and cross-faults. Note the regularity of the fault-trace. Topography of western half of map by Hodge, of eastern half by U. S. Geological Survey.

bia River lava plateau in north central Oregon, its contact with the Cascade Mountains, and the lower courses of John Day and Deschutes rivers (figure 2).

Shaniko Surface

All observers traveling over north central Oregon have been impressed by a montonous "plateau" surface determined by Columbia River basalt and now, in part, covered by a thin veneer of fluffy soil. This "plateau," or Shaniko surface, is a true expression of the underlying strata and

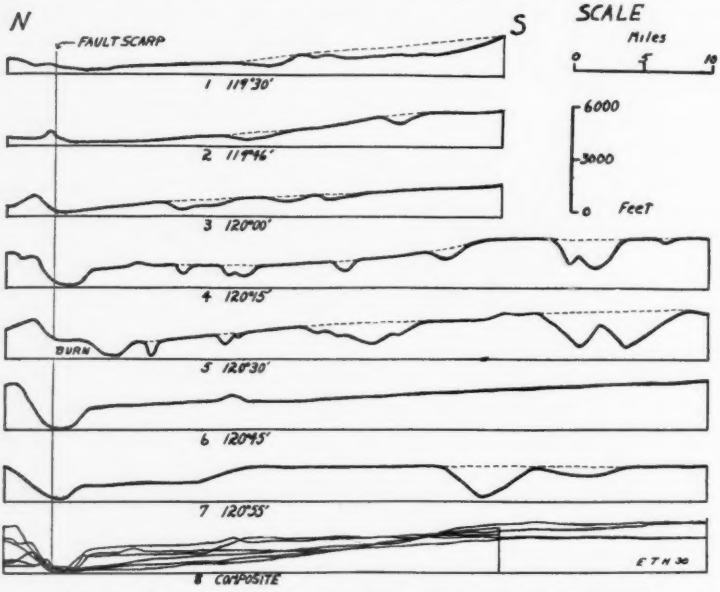

FIGURE 3.—*South-to-north Profiles of Shaniko Surface and Columbia Scarp*

Seven sections, from east to west, of the slightly eroded Shaniko surface, clearly show how it or its projection terminates at the foot of Columbia scarp. The composite section in (8) demonstrates the uniformity of this structure and topography. The Columbia River has developed close to and south of the foot of a steep escarpment against which a north dip-slope abuts.

extends regularly to the foot of Columbia scarp, against which it abuts. The sheer, steep face of the scarp over a distance of 80 miles rises to its crest, beyond which a second dip-slope, the Goldendale, extends northward (figures 2 and 3).

Columbia River has cut its canyon, here called the Arlington Canyon, close to the scarp at the northern termination of Shaniko surface. For

a clear understanding of the location of Columbia River a brief description of Shaniko surface is necessary. It is bounded on the south by an erosional scarp, called Antelope scarp, which in places is pronounced (figures 1 and 2). Antelope scarp faces south and the basalts which determine its rise above older rocks, being in contact generally with the John Day formation, exceptionally with the Clarno formation, and rarely with older formations. Shaniko surface, best developed east of Deschutes River, extends eastward for 60 miles. It has been named a plateau surface by all writers, and perhaps with propriety, in spite of the fact that the lavas composing it are seldom horizontal. Certainly it is a young surface. The evidences that it has not been profoundly eroded to a peneplain are: (1) the direct correspondence of the intervalley surface with the underlying structures, (2) the uniform thickness of Columbia River basalt formation, and (3) the fresh, unweathered sur-

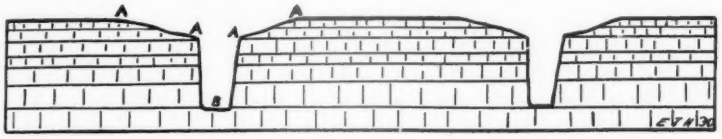

FIGURE 4.—*Canyons cut into a very young Shaniko Surface*

The earlier valleys, *AAAA*, are cut into only a small percentage of Shaniko surface, and usually are very shallow, rarely more than 100 feet deep. They were cut when the base-level for these streams was higher than at present. Such early valleys occur in the southern part of the area south of the meander belt. These upland valleys surmount the canyons and since no other valleys are found it is clearly evident that the canyon valleys are set into the bottom of the valleys and represent a continuation in the development program of the one and only set of valleys in this surface. Both are younger than Columbia fault. The valleys *ABA* are deep precipitous canyons throughout the area and from township 1 north to township 4 south are entrenched meanders. Farther north they are simple canyons cut in Shaniko surface, and like the canyon of Columbia River, are not entrenched meanders.

face of the basalt. If there had been a long period of erosion and especially if peneplanation had taken place, it is obvious that the surface would not be so uniformly parallel with the dip of the underlying basalt.

The concordance of Shaniko surface with the Columbia River formation is best demonstrated along the deep canyons of Deschutes and John Day rivers, to some extent of Columbia River, though along the latter pre- and post-Arlington erosion obscures it. From the mouth of Deschutes River for 25 miles south (to Tygh Ridge) the canyon rim is at the general elevation of Shaniko surface, which is determined by the topmost basalt flow.

Great noneroded, interstream areas, widely spaced valleys of moderate depth, and gentle valley sides prove that before canyon-cutting the Shaniko surface was in an early youthful stage. Valley profiles in the southern part of the area, where they are not complicated by superposition and entrenched meanders, also prove that a later rejuvenation took place and produced the deep, sharp canyons (figure 4). The interstream areas are broad and slope gently down toward the incised canyons. Standing at Shaniko the surface is so plainlike that one can look west to the Cascade Mountains, east and south into the "blue," and north to Columbia scarp. A few portions of a deep inset canyon may be seen off in the distance, but the other canyons are invisible. Thus the traveler is often disappointed in his efforts to reach within a given time an easily seen and apparently attainable objective because of canyons which remain invisible until their slope is reached. The John Day River canyon disappears in the apparently level surface and its presence would not be suspected by an observer looking east from Klondike. The surface to the south of Antelope scarp is entirely concealed. The area to the north stretches gently to Columbia scarp. Elevations near the following places illustrate the amount of slope in these areas:[3]

	Feet		Feet
Umatilla	550	Morgan	1,300
Irrigon	500	Pine City	1,500
Heppner Junction	600	The Dalles	2,000
Arlington	1,000	Seven-Mile Hill	1,800
Sherman	1,000	Friend	3,000
Big Eddy	1,000	Fossil	3,500
Echo	1,000	Shaniko	3,600

If the area now occupied by Columbia River gorge were filled flush with the adjacent surfaces, there would be a continuous north-dipping surface which would extend directly to the foot of Columbia fault-scarp (figure 3).

The northern remnants of Shaniko surface cut off by Columbia River will in this paper be spoken of as "benches." A description of the benches follows:

The largest bench is that formed by the Burn and Goodnoe flats (figure 9). It is over 6 miles wide and about 16 miles long. The surface is

[3] The writer has not had an opportunity to study the country to the east of Umatilla nor beyond 20 miles north of Columbia fault-scarp and makes no attempt to correlate his studies with work that has been done eastward and due north. It is hoped that future summers will permit correlation and agreement between findings in this paper and those facts found elsewhere.

strictly concordant with the level of Shaniko surface. Not only is the Burn bench concordant with Shaniko level, but it agrees with it in its general north and east dip. Thus the Goodnoe portion of the Burn bench has an average elevation of about 1,300 feet and the Burn proper has an average elevation of about 1,100 feet, that is, the dip is east, conforming in general with the structures in Columbia scarp.

About 2½ miles due west of John Day River mouth on the north side of Columbia River can be seen the Maryhill bench abutting directly against the scarp like a projecting shelf (figures 8, 9 and 10). This bench is not as wide as that of the Burn, being only about 2,000 feet.

The Wishram bench takes its name from the railroad town of Wishram which lies at its foot. Its eastern end begins just a little south of the head of Miller's Island in an abrupt wall and extends westward almost to north of Dillon, where it ends abruptly. The level of Wishram bench is about 1,000 feet and is concordant with Shaniko level; were it continued to the westward, it would become concordant with the eastern portion of the limb of Dalles syncline.

Structures beneath Shaniko Surface

The basalt which determines Shaniko surface is gently folded into several synclinal and anticlinal folds and each of these produce bulges and sags in the surface identical in extent and slope with the folds. Thus the Thirty-Mile Creek syncline, which extends across the area, produces the sag at Buck Canyon. This is also true of the east-west Mayville syncline.

The basalts beneath Shaniko surface dip about 1½ degrees, though dips as high as 6 degrees and as low as 1 degree occur. The few interruptions due to reverse dip are too infrequent to vitiate our general statement.

Near Shaniko the surface slopes northwest with the basalt. From Heppner to South Junction along Antelope scarp the basalt has the highest altitude that exists over the entire area. East of John Day River only one important interruption of the general north dip occurs in an anticlinal swell which extends from Cascade Mountains almost to Heppner. West of the John Day River an interruption of the great north dip-slope occurs near Maupin Mountain, where the dip-slope is northwest (in township 7 south, range 16, 17, 18, east) but changes to south farther west (township 8 south, range 15 east). From the vicinity of Shaniko the dip is northwest changing near Bakeoven to southwest. North of the Mutton Mountains, limited exposures show a dip-slope to Tygh Ridge.

FIGURE 5.—*Structure of Columbia River Formation parallel to Deschutes River*

This figure is a cross-section from the Mutton Mountains northward to Columbia River. It shows the general slope of Shaniko surfaces and illustrates the structural habit of this region. The structural habit shows a series of north dip-slopes interrupted either by sharp monoclinal folds or by faulting, from the crest of which another dip-slope extends to the north. Thus, a north dip-slope abuts against Tygh Ridge fault-scarp. The same is true of Gordon Ridge, and a similar fault is reproduced again at Columbia River, but on a larger scale.

Following the dip-slope west of Deschutes River, we find only three important major interruptions of the uniform declivity: Mutton Mountains, Tygh Ridge, and Gordon Ridge. North of Tygh Ridge extending northwest to Friend, Pine Hollow, and Dufur, the Columbia River formation forms the surface and produces a northwest gentle dip-slope. East of the Deschutes River the north dip-slope extends through Grass Valley, Moro, and Wasco (figure 5).

The general character of the small reverse dips is well illustrated in the section along Willow Creek, where all of the minor warps observed are lost when traced northeastward toward Alkali Creek or Columbia River (figure 6, at *a*). North of Columbia River and northeast of Roosevelt the dips are to the northeast, partaking of the general eastward dip.

Where minor streams have retrograded into Columbia scarp, the continuation of the north dip can be seen extending up these canyons (figure 6, at *b* and *c*). Alder Ridge expresses the north dip, and farther north and as far east as Big Horn Canyon the dip is also to the north, but to the east the dip changes gradually to eastward. Thus the tributary walls

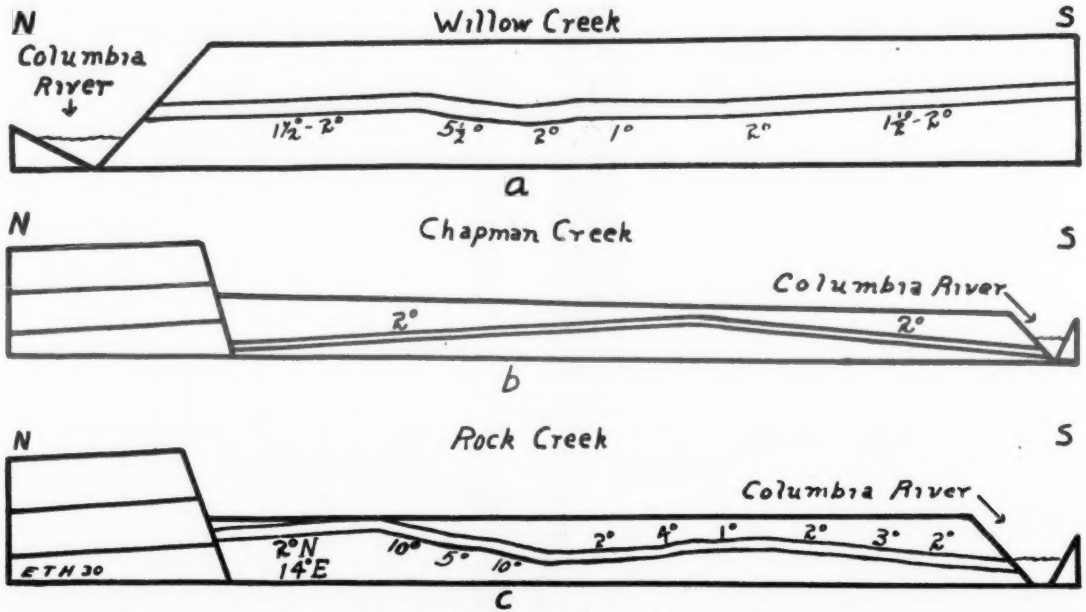

FIGURE 6.—*Warps in Shaniko Surface Lavas*

Willow Creek section shows the character of the minor warps in Shaniko surface. Chapman and Rock Creek sections show the continuation of the general north dip of Shaniko surface to the foot of Columbia scarp, and the minor flexures within it. In the case of the Rock Creek section there is a decided discordance at the point where the beds of the bench dip 14 degrees east and the scarp beds dip 3 degrees north.

of Alder Creek in each case show the north wall to be the steepest, and the south wall to be a gentle one, almost a continuation of the north dip-slope.

Columbia Scarp

A north dip-slope, here named Shaniko surface, conformable with the underlying structures extends across north central Oregon to the foot of a great scarp on the north side of Columbia River. The scarp, here called Columbia scarp, rises abruptly from the north edge of Shaniko surface. The basalts of Columbia scarp repeat the slope of Shaniko surface and continue northward in another north dip-slope called Goldendale surface.

Columbia scarp rises abruptly, sheer, and is interrupted by few imperfections and especially by no large cross-valleys. The scarp strikes north 75 degrees east (figure 7). Standing on its crest the writer beheld a

FIGURE 7.—*Sketch looking west, showing Columbia Scarp on the North, and Edge of Shaniko Surface on the south*

In the foreground is Quinton mosaic block lying at a lower level than the scarp crest or Shaniko surface. Also, in the foreground is a wall built of recent lava boulders and in the center may be seen the irregular surface of this young lava flow. In the mid-distance is a bench higher than Quinton bench called Maryhill bench. It is plainly evident that Shaniko surface, if projected north (right), would concord with the surface of Maryhill bench and that this surface, in turn, abuts against the face of Columbia scarp.

scene of grandeur spread out before him. The scarp face of Abert's Rim, in Oregon, generally accepted as a fault, is not more impressive. Columbia scarp is as striking as the panorama viewed by the writer in 1929 of the Great Rift Valley above Kijabe, in Africa, and shows greater regularity and abruptness. Far below, the narrow canyons cut in Shaniko surface by Columbia, John Day, and Deschutes rivers are almost invisible.

The evenness of the crest of Columbia scarp, and its gentle sinuosities prevent one from looking more than 5 to 10 miles along its face. The face, however, is steep and sheer, too steep to climb except in a few places where it is cut by draws. Along its entire course, only one road attempts

to scale it. Even where the face is breached by canyons, access to Goldendale surface is difficult. Its crest slants to the level of Shaniko surface at its eastern end (Paterson); to the west the crest ends against the easternmost fold of the Cascade Mountains known as Ortley anticline. The crest is highest where it breaks off from Ortley fold near Rowena (figure 12). The elevation of the crest north of Rowena is about 3,000 feet, north of Deschutes River about 2,500 feet, and beyond there it is maintained almost to a point north of Blalock. From this point eastward the elevation decreases more rapidly to 1,500 feet at Alder Ridge, 1,000 feet at Crow Butte, 800 feet at the west end of Canoe Ridge, and 350 feet at the east end of the same ridge, where Columbia scarp ends.

Shaniko surface adjacent to Columbia scarp descends gently to the east in a somewhat similar manner. The difference between their elevations is: near The Dalles 2,000 feet, near the mouth of Deschutes River 1,500 feet, north of Arlington 500 feet, north of Canoe Ridge 500 feet, and north of Paterson zero.

The plainness of Columbia scarp is in places destroyed by stream-cut V-canyons. Slight embayments occur where Maryhill Creek cuts across the scarp, another one occurs where Rock Creek cuts across it, and the other two are due to Artesian Coulée lying behind Crow Butte. It is very significant that these streams are so deeply incised that the plain face of the scarp extends to the very edge of their V-canyons.

The scarp face is partly concealed by many features. Erosional remnants of Shaniko surface and subordinate fault-blocks lie against its foot; against its slope lies the thin Arlington formation, a few small landslides, sand and silt blown and washed from Goldendale surface or interbedded ashes, and remnants of Recent lavas, which cling as pinnacles to the scarp face.

The old, worn and weathered appearance of the scarp in comparison with younger and fresher appearance of the walls of Columbia River canyon is due to the fact that the former is covered by washed and blown material and young lavas which veneer the edges and rest upon the benches of Columbia basalt.

The height of the crest of scarp is less affected by the erosion caused by canyons through the scarp from the back slope of Goldendale surface than by that caused by the canyons cutting into it from the north side.

The most striking feature of the scarp and the best evidence of its fault origin is its alignment, which may be observed from the scarp crest and also when the scarp is plotted a map. Figure 2 shows that the trace of the escarpment is not a straight line but follows a gently sinuous curve.

It strikes eastward, disregarding the erosional or structural features on either side, as shown by the following facts:

(*a*) Its gentle sinuosity ignores completely the larger curves of Columbia River, which compared with most streams is remarkably straight. Little curved as the river is, its curvature is nevertheless greater than that of the trace of the escarpment. In only a few places are the curves of the escarpment similar to those of Columbia River. In most of its course the river is apt to curve in one direction while the escarpment curves in the other (The Dalles, The Burn, Canoe Ridge). It seems evident that the factors which determined the curvature of Columbia River throughout this area are not the same factors which determined the face of the escarpment.

(*b*) Likewise the scarp strike is indifferent to the occurrence of the benches at its base which correspond in level with Shaniko surface. The portion of its face that emerges laterally from behind the highest benches is identical with the portion that is exposed above their tops.

(*c*) Whatever the structure south of the scarp may be, the scarp is unaffected by it. The most striking case is that of The Dalles syncline at the western end of Columbia scarp: this very definite structure strikes northeast-southwest and extends to and is terminated at the foot of the fault-scarp. All the other anticlinal or synclinal structures projecting northward from the south side of the Columbia River also come to an end at the foot of the scarp.

(*d*) The alignment of the scarp agrees with the following very significant topographic features, which will be described later: Triangular facets, valleys, truncated spurs, and the back edges of bench blocks. Thus, the valley that lies between Dalles bench west of Wishram and the high escarpment is directly in line with the scarp.

Evidence that Columbia Scarp is a Fault-scarp

General statement

A number of significant folds can be traced from Shaniko surface to the scarp where they terminate. Some of these folds that seem to be the result of the dragging motion along the fault face at the time of faulting exhibit a type of fault discordance; that is, the folding in the hanging block is usually greater than the folding in the raised block, and in practically every case the folds of one block fail to correspond to the folds in the other blocks. These different types of folds, separated by the fault-plane, are looked upon as very strong evidence of the fault. Below are described the various types of folds and their effects.

GENERAL EAST SLANT

In addition to the north component of the true dip the basalt beds show an eastern component especially in the eastern part of the area (figure 22). The amount of this east component is not the same in the beds of the north (Goldendale) and south (Shaniko) fault-blocks. Considering first the Shaniko block, it was found that from just west of John Day River

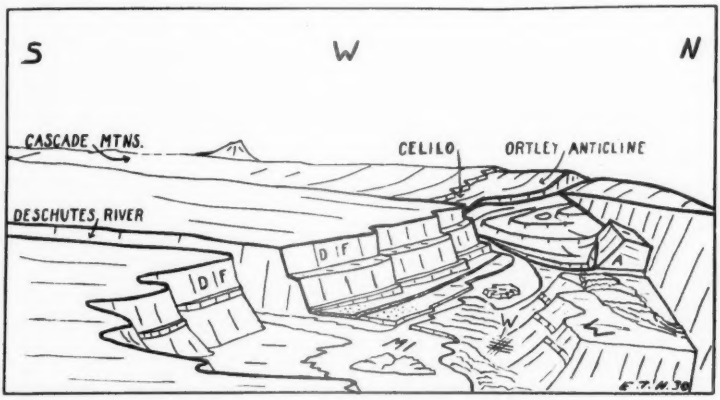

FIGURE 8.—*Looking west to west End of Columbia Fault*

MI, Miller's Island, an extension of the lava flow from the Maryhill bench. *A*, the isolated Avery fault-block; *D*, the Dalles syncline, which terminates against the fault. Deschutes River cuts through the Dalles formation (*DF*) into Shaniko surface. Columbia River forms rapids over lavas that probably came from vents back of Maryhill and Wishram benches. In the distance can be seen the Ortley anticline, now buried under the Dalles and Cascade formations, and which plunges to the south. This anticline is cut by the Columbia River fault on the north side of the river.

eastward (Klondike anticline) the east component remains about the same for 50 miles (Umatilla). West of Klondike the slant is towards the axis of Dalles syncline, west of which it again becomes eastward to the axis of the Ortley anticline. From the axis of the Ortley anticline eastward, disregarding the folds just described, there is a general descent to the east. For instance, from the axis of the Ortley anticline at 1,900 feet, the surface of the Columbia River formation drops to 1,000 feet near Biggs, and to 500 feet at Paterson.

On the north side of the fault the beds show none of the above folds. From the crest of the Ortley anticline eastward the east component of dip is more regular. The dip is largest from the axis of the Ortley anticline eastward to a point about due north of Celilo; from there it is

smaller until it reaches a point due north of Arlington, and still smaller east of that point. It is true that there are some minor flexures in the beds but their dips are much smaller than those of the beds to the south of the fault. These facts indicate that the fault is a slit, along which over the greater extent of the area the south side has sagged unequally.

LARGE BROKEN FOLDS

The larger folds in Shaniko surface terminate at the fault-plane; thus the finest evidence of discordance to be found along the entire fault is shown in the Dalles block (figures 22 and 8). This block is a synclinal structure striking south 25 degrees west. The beds begin to dip westward about 10 miles west of the mouth of Deschutes River, that is, where Columbia River bends southwestward (along the line of sections 10 and 11, 15 and 14, in township 2 north, range 14 east). This syncline is buried in part under the Dalles formation. It stops abruptly along the trace of the fault. It is true that in the escarpment the beds show a synclinal structure, but the dips are much smaller and the abrupt change in the amount of dip is plainly evident. The eastern limb of this syncline flattens out and forms an almost flat bench, which if continued eastward would connect with the Wishram bench (*W*). The two west parts of the west limb of the Dalles syncline, plainly evident on both the north and south side of Columbia River, becomes, toward the west, more and more concordant with the bedding in Columbia scarp, and finally, north of Rowena, they become absolutely concordant in the Ortley anticline.

The east limb of the Dalles syncline rises and forms a flat arch about 6 miles to the east, and 30 miles east attains the crest of the Klondike anticline. The east limb of the latter extends nearly 70 miles to Umatilla. This large structure has no close correspondence in the scarp.

At the east end of Columbia scarp, Golgotha, Crow Butte, and Canoe Ridge are folded, in part, into an east-west anticline. From the south, Shaniko surface extends to these and at their foot is either faulted or sharply folded. The difficulty of making an accurate determination of the facts in this case is due to the passage of the fault—if it exists—beneath the river. These folds, unlike the Dalles syncline, are parallel to the strike of the fault; hence the fault may end west of them. If so, they furnish evidence that here folding developed without faulting, but that farther west the movement required was too great and only faulting occurred.

In the scarp face the beds, though gently folded, do not all conform with these larger structures described above. For example, opposite the

Klondike anticline (Cliffs to Maryhill) the beds in the scarp show a large simple synclinal structure with an asymmetrically placed axis in the west. The west limb of this syncline rises on a 4-degree dip and ends, apparently faulted.

SMALL BROKEN FOLDS

In addition to the large structures just described there are a number of minor ones that appear to form evidence of a fault. It is the writer's theory that a hanging or south block dropping down will drag against the foot or north wall block, and thus cause the beds that are so dragged to be crumpled more or less. Moreover, a down-faulted block would probably be tilted so that its bedding would not agree with the uplifted block. Whether this theory be true or not the fact is that there is no consistent relationship in the structures of the beds of the blocks of the foot wall portion in comparison with the blocks of the hanging wall. In some places the upper beds have much greater dips than the underlying beds, and in other places they have similar dips; in still other places the lower beds are more greatly folded. In general it may be said that the beds in the lowest benches show a greater degree of folding than those in the higher benches or fault-scarp, and the greatest amount of folding is found in those beds close to the fault-zone. This, again, is not due to an unconformity between two series of lava flows, because where these beds, or their equivalents, are traced southward—for instance, up the Deschutes or John Day rivers—they show no evidence of an unconformity but present every type of evidence indicating a uniform series of flows which have behaved as a unit since the time of their deposition.

A number of these faint folds across Columbia River and, like the larger folds, end at the fault-plane. Briefly the following minor folds may be noted:

(1) Jones Canyon is crossed near the mouth by an anticline which may determine the Owyhee Rapids and extends north toward Old Lady Canyon and east across Little Willow Creek. (2) A fold extends almost east and west across lower Rock Creek, The Burn, and Lower Chapman Creek. (3) A fold swings northwest across the Goodnoe Hills, The Burn, crosses Chapman Creek, Four o'Clock Rapids, and runs up Blalock Canyon, the west limb of which continues several miles onto the high Smith Flats. (4) A very short anticlinal axis occurs in sections 9 and 5, township 3 north, range 18 east. This axis extends from the escarpment to the river edge. (5) An axis strikes southeast, running through section 9, township 3 north, range 17 east. This axis crosses Columbia River and runs up John Day River on the west side. The anticlinal structure

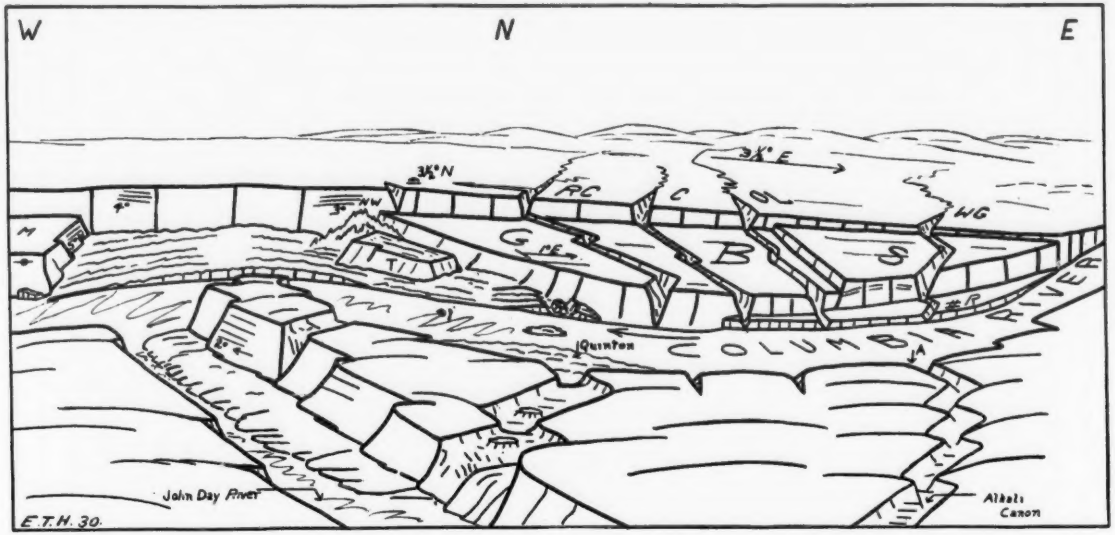

FIGURE 9.—*Diagram of View looking North from above John Day River*

The figure shows the extension of Shaniko dip-slope across the Columbia River as Burn bench (*B*), and the Maryhill bench (*M*); Smythe Block (*S*) is a portion of the fault mosaic that did not drop as low as *M*, *B*, or Shaniko surface. Roosevelt block (*R*) dropped still lower; Towal block (*T*) dropped and tilted to the east. The area between the Maryhill block and the Towal block is occupied by a Recent lava flow which extended across Columbia River as far as Quinton and probably extended up John Day River for 5 miles. In the northeast corner of this flow is a high-pinnacled mass which represents one of the vents from which the flow issued. The creeks which cut across the escarpment and the down-dropped blocks show that they have been developed since the period of faulting. Some of these are: *WG*, Woods Gulch; *OL*, Old Lady Canyon; *C*, Chapman Creek; and *RC*, Rock Creek. From the crest of Columbia scarp the beds generally dip northeast.

of the John Day bench at the mouth of John Day River is plainly evident when viewed from the high Columbia scarp. (6) In the same vicinity there are several warps where a sharp steepening in the dip occurs, as at section 7, township 3 north, range 18 east, and just west of Towal where a small syncline occurs.

Along Rock Creek a faint syncline and an anticline are exposed. The north limb of the anticline continues directly to the foot of the escarpment, where the beds strike 2 degrees north, but dip 14 degrees east. Directly north of the escarpment the beds are horizontal. The down-faulted Burn bench thus has a much greater dip to the east than the beds behind it. The Wishram bench dips north never more than 2 degrees, while the beds in the escarpment dip northward always more than 3 degrees.

FAULT MOSAIC

It is reasonable to expect that the movement of a normal fault of the magnitude of Columbia River fault would fracture the faulted edge of the down-dropped block, especially if the material is brittle basalt. Also we should expect that the fractured blocks would move downward variable distances and be separated from each other by minor faults. Some of these fault-blocks occur at the foot of the scarp and form a mosaic. The members of the mosaic will hereafter be called "blocks" or "fault-blocks" and when particularized they will be preceded by a proper name, and are shown in figure 8 at 5 and 1, figure 9 at *R, S,* and *T;* and figure 10 at *A,* and between *W* and *M.*

The writer has observed that other faults in other lava series show a similar mosaic along their courses, notably those of the Great Rift Valley of East Central Africa. That the mosaic blocks along the Columbia River fault are not due to erosion by the river is shown by their inconsistent arrangement along the river. The blocks that lie lowest are least numerous; the highest which were not cut off are most numerous, and mosaics *U, A, S,* and *T* are both small in size and few in number. Finally, it is to be noted that these mosaic blocks are most abundant and most broken in that portion of the fault-zone where the movement has been greatest, as west of Roosevelt.

The Roosevelt mosaic block is bounded on the north side by the 500-foot contour and on the south by Columbia River (figures 20 and 11). The western boundary occurs about 1½ miles east of Sundale, and at its eastern boundary the block ends in a sharp point just east of Roosevelt. This is the most perfect of the lower mosaics since it does not contain a cover of later lava flows. The true character of the Quinton mosaic block

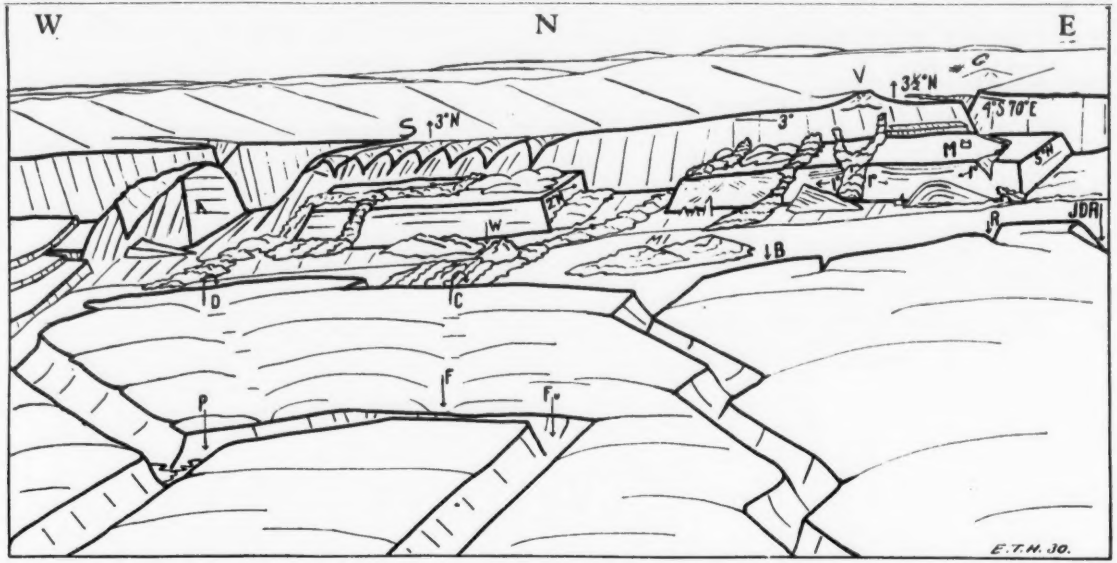

FIGURE 10.—*Diagram of View looking North from above Deschutes River*

The figure is a continuation of figure 9 down Columbia River. It shows the extension of Shaniko surface across Columbia River to Maryhill (*M*), and Wishram benches (*W*). Shaniko surface is covered by the Dalles formation, shown in the rounded hills. West of the Maryhill bench is Avery fault-block (*A*), an isolated fault-block. Columbia fault ends at Avery block. Another similar fault splits off farther north at *S* and continues west as the main fault to its final termination in the Ortley fold. The figure shows Recent lava flows that issued from the fault-zone, flowed over the benches and poured over their edges and into Columbia River, where they form islands at the present time. Another split-fault occurs near the eastern end of the Maryhill block. A volcano was built along the fault-zone and part of it still remains at *V*. *G*, Goldendale; *JDR*, John Day River; *R*, Rufus; *B*, Biggs; *C*, Celilo; *D*, Dillon; *P*, Petersburg; *F*, Fairbanks; *FU*, Fulton; *MI*, Miller's Island.

and of the Miller's Island mosaic block is concealed by later lava flows. The Roosevelt mosaic dips eastward which is in harmony with the structure on the eastern side of the Burn bench. However, close examination of the contacts shows that the two are at least topographically unconformable.

Just north of Roosevelt is the Smythe mosaic block (figure 9), which has a triangular form and is slightly lower than the top of the escarpment. The fault-scarp on its south side, that is, the one seen from Shaniko surface, is quite perfect, but the main Columbia River fault passes behind this block and continues due eastward, joining the Colum-

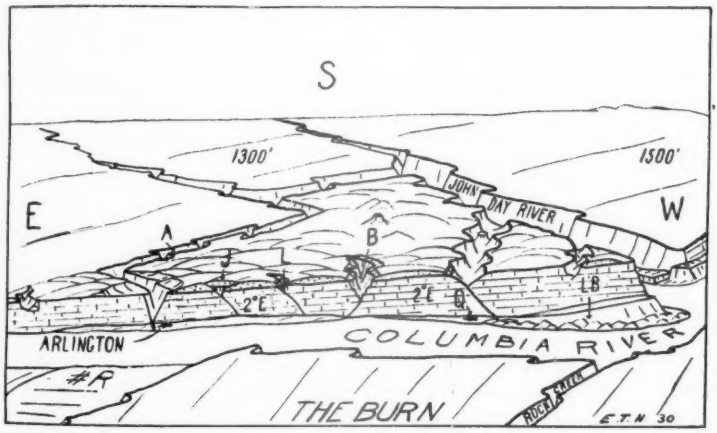

FIGURE 11.—*Diagram of Columbia Scarp, looking South from above The Burn*

The figure shows Shaniko surface concordant with The Burn. It also shows the east dip of the beds from the axis of the Klondike anticline. The rolling hills lying on Shaniko surface are Arlington formation; *R*, Roosevelt; *A*, Alkali Creek; *B*, Blalock Canyon; *Q*, Quinton; and *LB*, the lava flows that crossed Columbia River from the foot of Columbia fault to Quinton.

bia River 5 miles east (near Juniper Canyon). The northwest cross-fault is not so easily detected but must exist in view of the sharp topographic difference between the levels of the Smythe and the Burn benches.

Immediately west of the Burn bench is the Towal mosaic block (figure 9). This seems to be a continuation of the Burn level but shows a very sharp dip to the east and is separated from the Goodnoe portion of the Burn surface by a valley. It is significant to note that the direction of dip of this block is concordant with the direction of dip in the Quinton

block immediately below it. It may be a landslide block, but consideration must be given to the possibility that it is an independent mosaic block. Certainly the bedding is unconformable both with the bedding in the scarp, in the Burn bench, and in the Quinton block.

The north edge of the Towal mosaic lies south of the projection of the south edge of the Burn bench. The valley that lies between these two mosaics is directly in line with the scarp and may be a fault valley.

The Quinton mosaic block lies just west and extends westward to Cliff. Except in the vicinity of Quinton its exposures lie mostly on the north side of Columbia River (figure 9). On the south of Columbia River a very narrow strip begins 1 mile west of Quinton and continues westward more or less regularly (figure 11). No doubt the area beneath the present Columbia River is on the Quinton block, since it appears on both sides of Columbia River. The true nature of this block is concealed by later lava flows that cover it. The elevation of the Quinton block underneath the young lavas has not been determined. The lava flows lie between 400 feet and river-level and seem to have an unconformable relationship to the underlying beds.

Due south of the Quinton mosaic is the John Day mosaic block. The elevation of this bench is not in harmony with the Shaniko level on the south side, nor with the Maryhill and Burn benches, nor the Quinton mosaic block, but has an intermediate level. The John Day bench occurs at an elevation of about 350 feet (figure 11). This bench begins a short distance west of Quinton and extends along the foot of the south side cliff to a point just east of Rufus. The bench is practically continuous except at the mouth of John Day River, where it is eroded. This is a very narrow bench and shows near the mouth of John Day River a slight anticlinal structure. Whether this John Day bench is a true fault-block is uncertain—it may be simply a river-cut rock bench.

The Miller block lies between the Maryhill and Wishram benches. Its elevation is unknown because it is covered by young lava flows, but it can not be much above river-level and is perhaps below (figures 8 and 10).

The Avery block (figures 8, 10, and 11) is located just west of the Wishram bench. It is a small fault-block formed on the south by a continuation of Columbia River fault. Just east of it and of the west end of Wishram bench another fault splits off and continues westward behind Avery block, forming the prominent scarp which ends in the east limb of Ortley fold. Erosion has removed the material between the two faults east of Avery block; the west border is formed by a cross-fault.

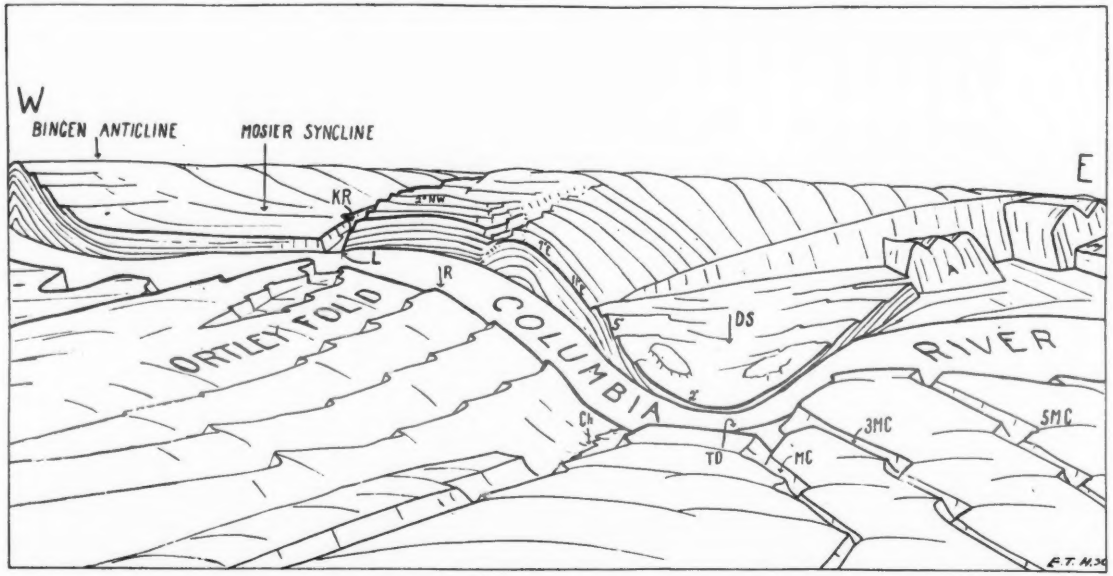

FIGURE 12.—*Diagram of View looking North from above The Dalles*

M, **Maryhill bench; *A,* Avery block. Note the fault facets on the face of Avery Block (*A*) and back of Maryhill bench (*M*). Columbia fault terminates in the Avery block but behind the block a second fault splits off and continues westward and finally ends in the eastern flank of the Ortley anticline. *5MC* is Five Mile Creek; *3MC,* Three Mile Creek; *MC,* Miller Creek; *TD,* The Dalles; *CH,* Chenoweth Creek; *DS,* the Dalles syncline, which terminates against Columbia scarp and strikes southwest under the Dalles formation shown in the foreground. A portion of the Ortley anticline, unbroken by the fault, extends westward to form the east limb of the Ortley fold, thus proving that the fault is later than the fold. The Ortley anticline is broken by two faults at Rowena (*R*) and Klickitat River (*KR*). To the west is Mosier syncline and Bingen anticline.**

The Dalles block (figures 8 and 12) is enclosed in the great south bend of Columbia River which has its apex at The Dalles. This block is unlike all of the others described in that its surface descends to the southwest. It is formed by a synclinal structure, the limbs of which, flattening out to the east and west, form a more or less flat bench. This bench is also rather flat in its upper portion where it abuts against the scarp.

TRIANGULAR FAULT FACETS

Triangular fault facets, all aligned to one plane, though not necessarily abundant are positive and direct evidence of our fault (figures 10 and 12). They occur near Wishram and east of Roosevelt.

Standing at the west end of the Maryhill bench and looking westward along the escarpment one sees a number of fault facets. To either side of the facets the scarp face may be fairly smooth, but on the facet itself the scarp face is a sheer smooth surface.

Going directly due north of Wishram and above the Wishram bench, and then along the road seven-tenths of a mile west, one comes to a facet. This facet lines up with eight other facets which extend to the very contact of the east limb of the Dalles syncline. Continuing the strike of these facet faces westward it is noted that they strike into a small valley that lies between the contact of the east limb of the Dalles syncline and the scarp face. The facets, the contact, and the scarp face are all in line. These are typical scarp facets, perfectly preserved, all striking in the same direction and so flat and smooth and perfectly aligned that if a board long enough could be found, it could be laid flush against the faces of all of them. In this section the facets make up practically all of the exposed scarp above the bench. Between the facets are V-shaped valleys, but the bottom of the facets are in union. The writer has had the opportunity of examining the typical triangular facets on the Wasatch escarpment and elsewhere, and to him these appear to be just as perfect. In fact, those to the north and west of Wishram are almost ideal from the standpoint of diagramatic presentation.

Less perfect triangular facets occur also between the Maryhill bench and Wishram bench. Viewed from across the river they show lying between them V-shaped valleys wherein the bedding plane may be perfectly seen (figures 10 and 11).

Another series of facets occur on the fault-scarp facing the Columbia River for 4 miles east of Roosevelt. In order from west to east the first three are perfect triangular facets, and beyond them lie three eroded triangular facets. Thus we have on the fault-scarp in the area under

consideration a total of 15 excellent triangular facets. In all cases these triangular facets line up with each other and are in line with the fault-scarp and with other topographic features.

Portions of the scarp are so perfectly preserved that no facets have been developed, particularly in a 6 to 7-mile section, 4 miles east of Maryhill (in range 17 east). The fault face in several places is so plain, so smooth, so straight and perfect that one can lay his hand directly upon it. Other portions of this scarp east of Roosevelt also appear to be too young to have developed facets.

TRUNCATED SPURS

Truncated spurs east of Roosevelt, where the Columbia River for 2 miles follows directly at the foot of the fault escarpment, are considered as remnants of triangular facets developed along this particular course of a fault-scarp where intermediate valleys have developed so large that they dominate the face of the scarp.

FAULT-ZONE

The writer and his student assistants have made a diligent effort to locate the trace or zone of the fault, but so far without much success. In a fault of this magnitude one should expect to find a very wide zone of gouged, brecciated, and broken-up material. However, the wash, wind-blown material, landslide material, and other features make it very difficult to determine just what lies at the contact between the mosaic blocks and the fault-scarp. The low-lying mosaic blocks are covered not only with the materials mentioned, but also with later lava flows, which conceal the nature of the faulted zone.

However, direct evidence of the fault was found in a few places. Thus, a very rotten basalt lies between the Maryhill bench and the fault-scarp (2.6 miles east of Maryhill along the road, just at the point where the blocks contact with the fault-scarp). The road from Maryhill to Goldendale, at the fountain at the head of the grade, passes directly across a shear-zone (figure 13). This zone shows from north to south 30 feet of white clay gouge in contact with 25, 3, 5, 8, and 4 feet respectively of solid rock separated by thin shear-zones. Also, west of Wishram where the fault-scarp passes behind the Dalles syncline there is a narrow valley parallel with the fault-scarp face which must be determined by some soft material. Similar narrow valleys lie behind the isolated Avery mosaic and behind the Towal mosaic blocks.

The absence of a continuous, easily identified fault-zone is not in itself very significant, since in most large faults such zones are equally hard to find. In the Great Rift Valley of East Central Africa, the faults dislocate a series of lavas very similar in their brittleness and general character to those here under discussion, and there fault-zones are almost impossible to find. In fact, from the observations of the writer, it can be said that the evidence for a fault along Columbia scarp seems to be much better than along much of the Great Rift Valley, where only topographic evidence and some slight structural evidence is available.

THROW OF FAULT

The faulting was not sufficient to expose any beds underlying the Columbia River formation, and the throw is thus less than the thickness

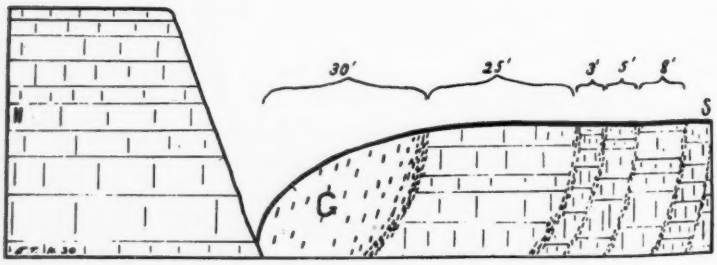

FIGURE 13.—*Section of Fault-Zone North of Maryhill*

The section is from the top of the grade where the road crosses the scarp from Maryhill to Goldendale. The fault-zone consists of 30 feet of gouge (*G*) and 25, 3, 5, and 8 feet, respectively, of basalt separated by gouge zones.

of this formation. The thickness of Columbia River formation in different parts of Oregon has been variously estimated to be between 2,000 and 5,000 feet, although our studies indicate that it is much less, even as little as 500 feet in places. Along Columbia River the thickness is at least 3,000 feet. Since there has been little erosion of the surface of Columbia River formation in this part of Oregon, then the crest of the escarpment may be taken as the topmost surface and from it we can estimate the amount of throw. Thus, north of The Dalles, the height of the scarp is about 3,500 feet, north of Rufus 2,400 feet, north of Arlington about 2,400 feet, and at Coyote zero. Hence, the amount of throw varies along the fault. North of The Dalles it is about 2,700 feet, north of Rufus about 1,200, north of Roosevelt 1,200, and zero at Coyote.

OPENNESS OF FAULT-ZONE AND YOUNG LAVAS

Young lavas, which can be traced to the foot of Columbia scarp, are considered excellent evidence of a fault (figures 9, 10, and 11). Four areas of these lavas have been carefully investigated and in each area the only source from which they can be shown to have issued is along the fault-plane. The line connecting the vents of all these flows is identical with the trace of the fault.

OTHER FAULT-SCARPS IN OREGON

The sequence of structural and topographic features already described is found on a smaller scale in north central Oregon. Three folds, each almost parallel with Columbia scarp and each faulted on the south side, occur in Shaniko surface. In each a north dip-slope extends directly to the foot of a fault-scarp, formed in the south limb of a fold, from which a north limb extends northward to the next fault or asymmetrical fold (figure 5).

No attempt will be made here to describe the structures in north central Oregon. It is sufficient to point out that the northernmost structure is Gordon Ridge, an almost east-west monoclinal fold, faulted in the south side. Farther south is Tygh Ridge, a larger monoclinal fold with a scarp at its eastern end sharper than Gordon Ridge. Its east and south sides are faulted. The largest fold with a fault-scarp on the south side is known as Mutton Mountains. Each of these folds or scarps extends eastward into Shaniko surface. Figure 5 shows also other unnamed flexures lying between those mentioned. They seem to demonstrate a common tendency to fault, or fold and fault, in parallel structures in north central Oregon.

Other Theories of Origin of Scarp

GENERAL STATEMENT

During the many years that the writer has studied the geology of north central Oregon many theories have been held and tested in explanation of the origin of the great fault-scarp on the north side of Columbia River and the benches at its foot. Some of the theories considered are presented below.

LANDSLIDES

From the bottom and the south side of Columbia River canyon the benches at the foot of the fault-scarp resemble downslid blocks. This

theory is eliminated when the benches are viewed either from the scarp crest or from Shaniko surface, because from such locations it is clearly evident that the benches are on the same level as Shaniko surface. In addition, the benches are composed of the same rocks as, and agree essentially in their structure with, those that underlie Shaniko surface (figure 14).

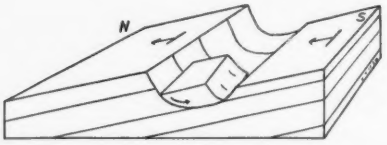

FIGURE 14.—*Diagram of Landslide*

The lack of tilting and the perfectly conformable relations with Shaniko surface prove that the benches are not landslide blocks.

ERODED MONOCLINAL FOLD

A theory that the fault-scarp was due to erosion of a monoclinal fold connecting Goldendale and Shaniko surfaces was investigated. The theory was suggested by the fact that to the south in Shaniko surface several partially faulted monoclinal folds were found. Also, the suggestion of Bretz[4] that Columbia River follows a syncline through eastern Oregon made the theory plausible.

The theory was checked by examination of the canyons eroded in the benches at the foot of Columbia scarp, especially those that extended beyond into Goldendale surface to the north (Rock, Chapman, Old Lady, Wood, and Juniper creek canyons). In these canyons the persistent north dip was found except at the fault-zone, where in some places slightly disturbed beds were observed. The west end of the fault cuts into an anticline (Ortley) which strikes about 45 degrees to the fault trace. The eastern end of the fault appears to merge into a small anticlinal fold (Crow Butte, Canoe Ridge, and a ridge south of Golgotha Butte) (figure 15).

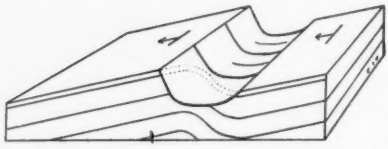

FIGURE 15.—*Diagram of eroded monoclinal Fold Scarp*

If true the benches on the north side of Columbia River should show monoclinal structure, which they do not.

SCARP SAPPED BY WEAK BEDS

Beneath the Columbia River basalt (Miocene) lies the weak John Day formation (Oligocene) which 50 miles to the south has produced a reces-

[4] J. Harlen Bretz: "The Dalles type of river channel," Jour. Geol., vol. 32, p. 129, 1924. Bretz says that from The Dalles, "the Columbia River for 125 miles upstream and a few miles downstream flows in the bottom of a broad syncline and the group of rapids '(*The Dalles*)' is located on a minor upwarp of the floor."

sion scarp, here called Antelope scarp, by sapping as shown at *S* in figure 1. Over the basalt in the Cascade Mountains lie the weak beds of Dalles, Satsop, Cascadia, and Rhododendron formations (Pliocene or older Pleistocene) on which lie the resistent lavas of Cascade formation (Lower or Middle Pleistocene). The theory of sapping by the above weak beds or interbedded pyroclastics in the basalt was easily excluded because the bold scarp is free of cover except for wind-drifted soils. The fault-scarp was found to consist entirely, except for some later lavas plastered against it, of Columbia River basalt and in it were found only a few thin and short layers of interbedded ashes (figure 16).

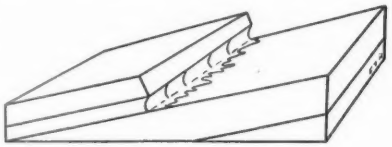

FIGURE 16.—*Diagram of Scarp sapped by weak Beds*

SCARP ON ONE SIDE OF SUBSEQUENT CANYON

The development of a canyon as shown in figure 4 is a variant of the preceding theory. It was quickly dismissed because of the absence of weak beds (figure 17).

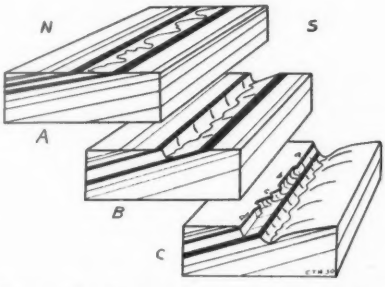

FIGURE 17.—*Diagram illustrating the Development of a Scarp, Canyon and Benches on inclined weak Beds*

The figure illustrates the assumption that the Columbia River accidentally flowed over the surface of a soft interbasalt formation. Entrenched on this soft formation it became superposed on the hard beds and developed a valley as shown in *B*; *C* shows the continuous stages in the development of this valley, wherein *a* is a simple scarp wall produced when the stream was first inset on the hard beds lying below the soft beds; *b*, the soft bed cut away from beneath the overlying hard beds, undersapping them, and producing a cliff and bench; *c*, the scarp more highly developed but irregular in its front; and *d*, the perfectly developed cliff. The objection to this theory is the absence of an extensive soft bed.

RECESSION OF WEAK BEDS

Folds in the benches not visible in Columbia scarp suggested an unconformity, which in turn led to a theory that if the lavas above the unconformity were weaker they would have been eroded back to form a scarp (figure 18). This theory would have explained the concordant level of the benches with Shaniko surface, but not the regularity of Columbia scarp. Diligent search in the canyons of the benches produced no evidence of an unconformity (figure 6 at *b* and *c*),

and petrographic sections of the fault-scarp revealed no essential difference in the lavas, the theory was therefore abandoned.

ERODED EDGES OF FLOWS FROM THE NORTH

If a series of younger lava flows from the north ended more or less regularly at some east-west line approximating the present Columbia River site or even farther south, and if the whole surface had been tilted north, then erosion of their edges, from the trough so formed, would have produced an escarpment (figure 19). Also, it is possible that the younger lava would have the same composition as the older ones, giving to a composite scarp a homogeneous appearance. This theory was eliminated because of the regularity of the fault-scarp. Thus, a scarp cut from a lava front should be irregular, fitting the path of the stream which carved it. The fault-scarp is straight and in two places lies 6 miles from the river. Further, such an escarpment would have rock benches cut on some of the flows, which would lie at a higher level than Shaniko surface. Also, the benches should gradually come to an end. The benches that we find end rather abruptly; their right-angled ends run directly into a bold scarp face which seems to pass behind the bench. Finally, there is no evidence of flows having come directly from the north. True it is that north of the scarp there appears to be some evidence of an intercanyon flow following an east-west valley, but this flow can not be traced to the scarp face; in fact, it occupies a valley carved in Goldendale surface.

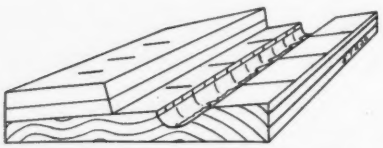

FIGURE 18.—*Erosional Scarp in younger weak Beds*
All evidence points to a homogenous series of lavas.

INTERCANYON FLOW FLUSH WITH SHANIKO SURFACE

This theory was suggested by studies in central Oregon where young lava flows lie on, and in places fill canyons flush with, an older surface. The theory is worthy of consideration because the scarp, the base of which is buried, could have been formed otherwise than by faulting, and also because it would explain the concordance of the benches with Shaniko surface. Such an intercanyon flow might have filled a narrow or broad valley as shown in figure 20. This theory was found not true for the following reasons: (1) The rocks of the "intercanyon" are identical in composition with those of the scarp. (2) The degree of alteration of the

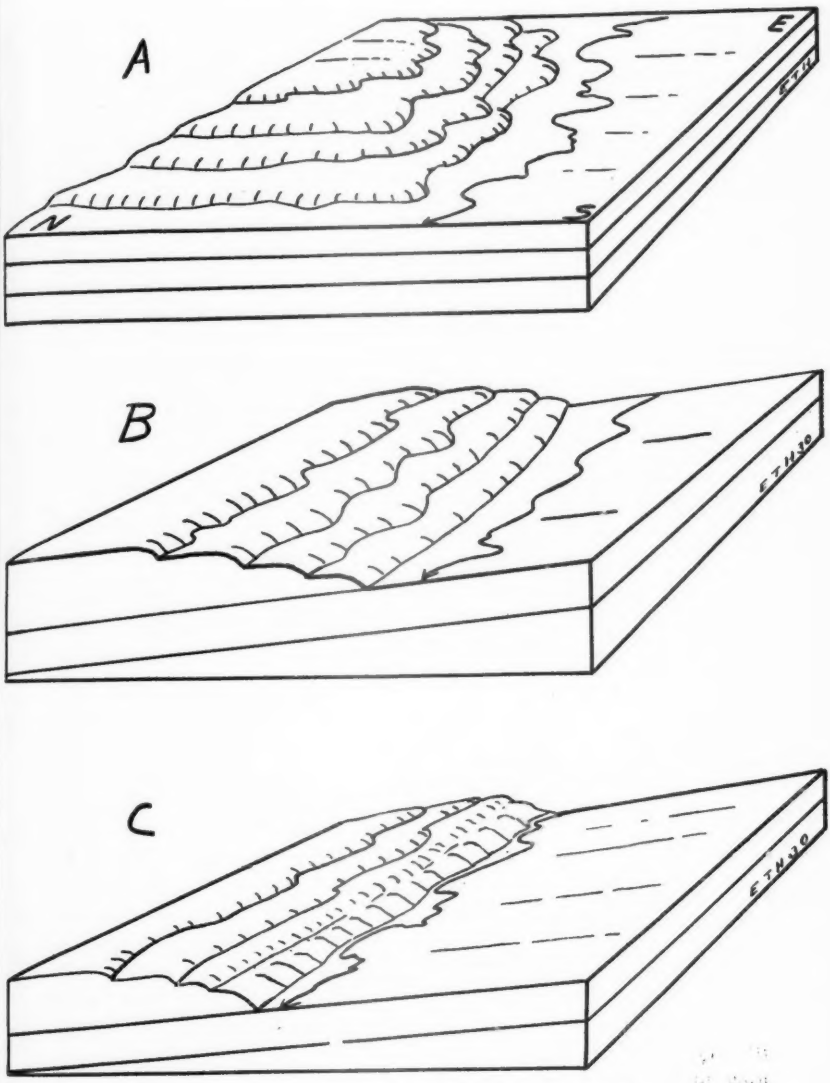

FIGURE 19.—*Scarp eroded in the South Edges of Lava Flows*

A shows lava flows from the north; *B*, the surface tilted northward; and *C*, the erosion of the edges northward. The objections to this theory are: First the beds in the scarp are identical in character and composition to the beds of Shaniko surface. Second, erosion of such flows would not produce a straight and uniform scarp.

cliffs in the "intercanyon" is identical with that of the cliffs of the scarp in spite of the young and steeper appearance of the former. (3) At the west end of Columbia scarp (The Dalles), the south side canyon wall can be easily traced westward to a point where it changes its dip and forms a syncline which itself is part of the anticline to the west (Ortley); this anticline in turn crosses, joins, and becomes an integral part of the scarp. (4) Finally, the unconformity between the "intercanyon" and lavas of Shaniko surface can not be found in the splendid canyons of Deschutes and John Day rivers.

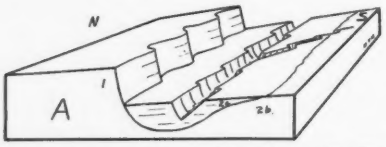

FIGURE 20.—*Intercanyon Flow flush with Shaniko Surface and partially burying the Base of the Escarpment*

The figure illustrates the theory of an intercanyon flow that filled an old valley. The figure is drawn so that the benches on the north side of Columbia River are concordant in level with Shaniko surface. The objections to this theory are: The unconformable relations found between the intercanyon flow and the older surface should be but are not found in the canyons of Deschutes or John Day rivers. The composition of the lavas of the benches, the scarp, and Shaniko surface are identical. Finally, we still have to seek some explanation as to why the scarp face and its crest is so much higher than Shaniko surface.

FAULT THEORY

The fault theory meets all the requirements of the known facts (figure 21).

GOLDENDALE SURFACE

From the crest of Columbia scarp the Goldendale surface, similar to Shaniko surface, extends northward. From the crest of the scarp Goldendale surface is beautifully shown. As smooth as Shaniko surface, it begins at the very crest and slopes gently northward. It corresponds accurately to the dip of the basalt which determines it. Near the crest its slope is 4 degrees, which gradually lessens until at a distance of from 2 to 5 miles from the crest it is only 1 degree or even less.

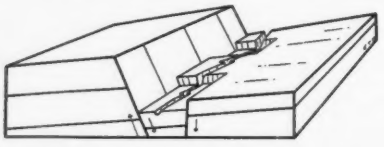

FIGURE 21.—*Diagram illustrating Fault-Scarp, concordant, down-dropped Surfaces, Fault Mosaic Blocks, and Maryhill Trough*

Only a few streams have cut back into Goldendale surface: Glade, Alder, Juniper, Old Lady, Chapman, and Rock creeks. Their canyons all cut directly north into the scarp face except two, one at Maryhill and the other about 5 miles west of Maryhill.

The sinuosity of Columbia scarp forms on Goldendale surface a series of scallops which rise higher the farther they project to the south. A

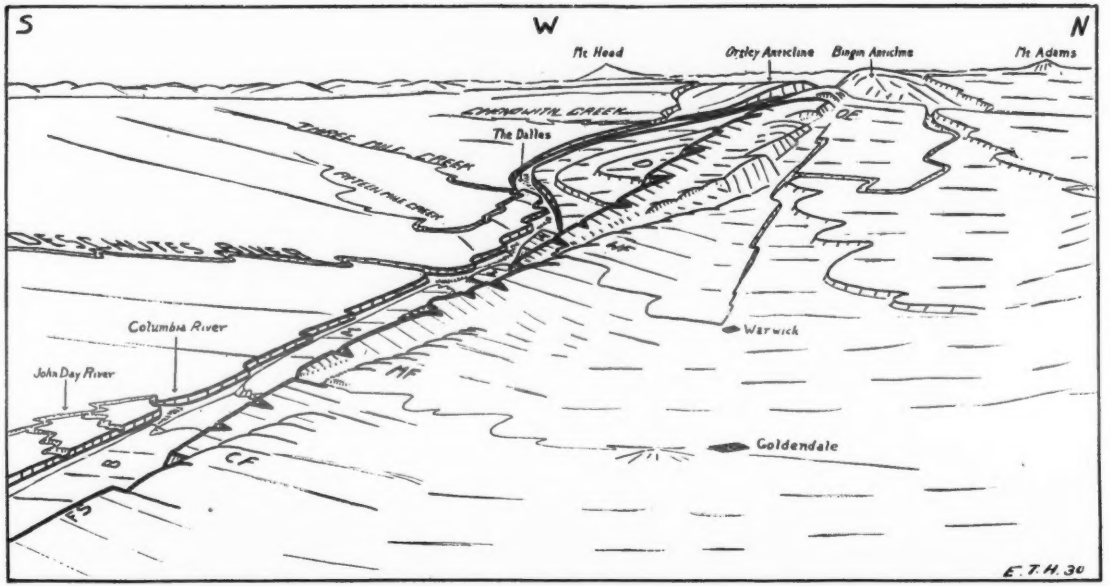

FIGURE 22.—*Diagram of Shaniko Surface, Columbia Fault, and Goldendale Surface*

Diagram is from just above Columbia scarp crest looking west. *FS* is the scarp crest, below which lies Burn bench (*B*) concordant with Shaniko surface. John Day and Deschutes rivers flow down Shaniko surface, but Fifteen Mile Creek and Three Mile Creek flow down a later slope determined by the superposed Dalles formation. Note the old outlets of John Day River into Columbia River. *M*, Maryhill bench; *W*, Wishram bench; *A*, Avery fault-block; *D*, The Dalles bench, a syncline terminating against the foot of the scarp; *CF*, Chamberlain Flat and a split-fault; *MF*, Maryhill split-fault; and *WF*, Warwick split-fault. Far to the west are offset faults (*OF*) which along with the Warwick fault cut the Mosier anticline. Columbia fault also cuts this anticline. The Ortley and the Bingin anticlines extend southwestward under the Dalles formation.

good illustration of this is Chamberlain Flat, the name given to the upper portion of the smooth slope extending south to the edge of the crest (figure 22 at *C F*). It projects about 2,000 feet south and rises to 2,700 feet—200 to 300 feet higher than adjoining areas.

Faults in Goldendale Surface north of Columbia Fault Crest

Minor faults split off from the major Columbia fault at five different places (north of Moonax, near the upper part of Chapman Creek, at Chamberlain flat, north of Maryhill, and northwest of Wishram) (figures 22 and 9). Four of the branch faults pass behind the crest of Columbia scarp, where they reproduce the same features found on the south side of the escarpment, that is, fault cliffs, alignment of fault facets, brecciated material, dislocation of beds, and a general alignment of topographic features. The split-faults interrupt the gentle north dip-slope of Goldendale surface, but beyond them the slope continues for many miles to the northward.

Each of the split-faults produces a valley at the point where the minor fault joins the main fault. Each valley is usually very narrow and straight and turns off and follows the split-fault (figures 22 and 10). At the point where the valley opens out onto Columbia scarp it breaks down the defenses of the latter, so to speak, and so permits cross-scarp streams to develop, thus breaching the scarp. Such breach valleys, following the split-fault, are the common entry way for roads that cross over the scarp to Goldendale surface. (One at the head of Chapman Creek at Chamberlain flat, one at Maryhill pass, and one running from Grand Dalles northeastward to Warwick).

The valleys, determined by the secondary faults, take off at a smaller angle than the streams consequent on Columbia scarp. Large streams consequent on Goldendale surface, working southward, generally cut into the fault valleys. Small, intermittent and consequent streams have cut into the south wall of the fault valleys and have produced a series of hills all in line (figure 22). The hills have the shape of a slice of a sphere truncated on the south edge or fault-valley side. The south side of each hill is steep, and the north side is a continuation of the north dip-slope. These hills always become smaller westward along the termination of the fault in Goldendale surface; they look like a series of landslide hills except for the facts that they have perfect drainage directed towards Columbia scarp crest and that they preserve perfectly the northern dip of the beds. Beyond the hills and beyond the extension of the valley a series of fault facets are to be seen, usually on the north wall of

the secondary fault-scarps, and beyond the fault facets a good fault-scarp may extend.

The split fault extending westward from north of Maryhill is the only one showing facets (figure 22). The three facets are on the ends of spurs between consequent streams coursing from Columbia scarp crest northward to the secondary fault valley.

Three of the secondary fault-scarps face north and one faces south. The south-facing scarp produced the Smythe mosaic block, one end of which is 3 miles south of Columbia scarp. The Smythe mosaic block is a step in a step-fault. The other mosaic blocks lying between the

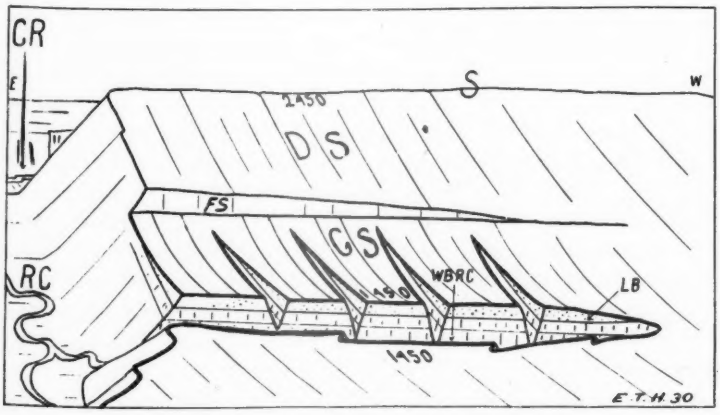

FIGURE 23.—*Diagram of secondary Fault across Rock Creek*

The view is from the east side of Rock Creek looking south toward the crest (*S*) of Columbia scarp 2,450 feet high. *CR*, is the Columbia River in Maryhill Trough; *DS*, Goldendale surface which conforms with the bedding of the basalt, and which extends from 2,450 feet down to 1,450 feet in the foreground; *FS*, a fault-scarp due to a split-fault which extends across Rock Creek and unites with the main fault farther east.

north-facing scarps and Columbia scarp are horsts or uplift blocks, the greatest uplift being at the point where the two fault-planes unite, and the least at the other end. Just how far west each split fault extends is unknown; each is plotted only to the limit of a definitely determinable scarp face.

The Rock Creek fault has no scarp east of Rock Creek—only a valley showing the course of the split fault—but a definite scarp is shown for almost 5 miles west of Rock Creek (figures 2 and 23). The west tributary of Rock Creek does not follow this visible fault-zone, but lies to the

north of it. However, a fine fault-scarp is plainly evident to one looking southward from the 1,450-foot level.

The Chamberlain fault begins almost directly north of John Day River. This fault has no definite scarp but is evidenced on the north side by a series of small hills, all in line and repeating the dip-slope, which here is to the northwest.

At the Maryhill-Goldendale road gap another fault splits off; it shows no scarp and swings northwestward for 2 miles. It exhibits a narrow valley in its western part and a series of hills in line, the north sides of which repeat the north dip-slope.

Almost due south of Warwick a great secondary fault begins, called the Warwick fault (figure 18). To the south of Columbia scarp is the small Avery fault-block, dipping 6 degrees to the north, which is isolated by Columbia fault and bounded on the south by a projection of Warwick fault (figures 8, 10, and 12). Warwick fault crosses Columbia fault behind the latter scarp and produces first a narrow valley, then a series of hills in line, next some prominent triangular facets, and finally the great scarp on the north side of Stacker Mountain. The beds on the top of Stacker Mountain dip 18 degrees south, while those of the down-dropped block at the north foot dip about 2 degrees south, thus proving a disconformable relationship due to the fault. The dip from Columbia scarp is 5 degrees north, so that the block between it and Warwick fault has been squeezed between the two faults to form a synclinal structure in the horst block.

From Stacker Mountain to Klickitat River the Warwick scarp is made up of a series of north-facing scarps, each one of which as followed west is successively offset more to the south. This suggests a series of north and south cross-faults of a later date, but of these only one, just east of Lyle, has been determined. The first scarp west of Stacker Mountain begins 4.8 miles west of Warwick and continues to 7.8 miles; thence it is offset to the south about 2,000 feet, and from there a scarp continues to 9.6 miles west of Warwick. The first scarp becomes lower to the west and its place is taken by the north limb of a fold. The next scarp appears to be the cut-off edge of the north limb of a fold. Beyond it about 10 miles west of Warwick and continuing for a distance of 7 miles, a perfect fold replaces the scarp. This anticlinal fold is offset to the south and is separated from the area to the east by a sharp valley. This valley lines up very closely with Lyle fault on the north side of Columbia River east of Lyle, and it may be the northern extension of this fault.

Along Columbia River, parallel to these offsets, Columbia fault is not shown. Instead, Ortley anticline crosses Columbia River and north of the river veers off to the east. It may be that the portion of Columbia fault which ends east of Lyle is the split fault, while the main fault continues, farther north, as Warwick fault for an indefinite distance. The successive offsets of Warwick fault would account for the change in strike of Ortley anticline from north 45 degrees east to north 75 degrees east. Heavy timber and the presence of a thick overlying deposit of later Cascade andesite soil make it impossible to determine the continuation of this possible fault north of the Ortley fold. Farther west, beyond the Klickitat River, the Mosier fold is apparently unfaulted.

In addition to the features just mentioned, zones of brecciated and fractured material occur just west of Stacker Mountain in a cut in the road from Warwick to Lyle. About three-tenths of a mile from the west side of Stacker Mountain were found two zones of fractured and brecciated material, one over 200 feet wide. Also, 5.2 miles east of Warwick on the road to Grand Dalles, in line with the fault-zone, may be seen material that could be considered fault breccia.

Studies have not been made to determine the character of the fault-scarps that swing out to the northwest. The topography suggests the possibilities (1) that they pass into a valley which has since been filled by an intercanyon flow, or (2) the country to the north, which is a great flat plain, may be a continuation of the north dip-slope and hence is unfaulted. Such evidence as exists suggests that these faults die out and are in the nature of hinge-faults with the greatest movement towards their junction with the great Columbia fault.

Coriba Surface

The Shaniko surface extends westward to the Cascade Mountains, where as it passes under younger formations its name is changed to Coriba surface. This name is mnemonic for Columbia River basalt, which determines the surface.

West of Deschutes River a long narrow area of Shaniko surface extends up Fifteen-Mile Creek almost to the east line of range 12 east. Farther west the Dalles and Cascade formations cover Shaniko surface and in the Cascade Mountains it is completely buried, except in some deep canyons, by Dalles, Cascade, and other formations. In the Cascade canyon, a name given to that portion of Columbia River canyon in the Cascade Mountains, may be seen several folds of which the highest, Wyeth, is crossed by the canyon at 3,000 feet elevation. These folds all

plunge to the south. (Wyeth anticline, which 5 miles north of Columbia River is at 4,500 feet elevation, at the river is at 3,000 feet, and 10 miles south is below river-level.) Also Ortley anticline 2 miles north of Columbia River (township 3 north, range 13 east) has an elevation of 2,700 feet; on the south cliff of the canyon (back of Rowena) it is at 1,800 feet; and 5 miles farther south (township 2 north, range 12 east) it is at 1,200 feet. Still farther southwest it passes under later formations and does not emerge again as a recognized structure. The above measures show that the present course of Columbia River is cut into high portions of the folds.

Farther south Coriba surface is a lower level which appears to connect with continuous lowlands in Shaniko surface.

Thus, Dalles syncline strikes south 45 degrees west and the Maupin–Thirty-Mile syncline strikes almost east and west. The projections of these two synclines would meet at Clear Lake (southwest corner of township 4 south, range 9 east), and 13 miles south of Mount Hood. Between these two synclines is the Tygh Ridge anticline, which plunges steeply to the west in harmony with the coalescence of these two synclines.

Further proof that Dalles syncline continues under the Cascade lavas is found in the fact that small islands of the Columbia River formation crop out on the east slope of Cascade Mountains. North of Tygh Ridge the dips are to the northwest, gradually changing to west as they are traced down the west side of Deschutes River. Thus the northwest dip was found in exposures of basalt on the east side at Dalles syncline, beyond which the dip changed to southeast. Further, the outcrops of the Columbia River formation are smaller and fewer along the axis of the projected Dalles syncline than to either side, even than on the northwest side where the later lavas are very thick.

Standing on the east side of Deschutes River (say in township 5 south, range 14 east) and looking westward in this range of townships, or in the vicinity of White River, the observer sees a low sag in the Cascade Range. This sag may overlie a former depression in Shaniko surface toward which flowed later lavas but which they did not completely fill. Moreover, the deep canyon of White River, in the sag, does not expose the underlying basalt. The writer's unpublished map of the Mount Hood area shows that west of Clear Lake, south of Mount Hood, and southwest of Mount Hood, the Columbia River formation lies at a low elevation owing to erosion or to structural conditions, and was a lowland just

previous to the deposition of the pyroclastics and lava flows of the Cascade formation.

To illustrate this last statement, let us take a section due south from Stevenson and skirting the west side of Mount Hood. The Columbia River formation in Columbia River gorge is 3,000 feet in elevation; at Bull Run River, to the south and slightly west, the greatest height is 1,700 feet; at Alder Creek in the Sandy River valley to the south it is at about 1,100 feet elevation; farther south, on the north side of Eagle Creek just below Wildcat Mountain it is 2,500 feet; and on the south side (2½ miles farther south) the Columbia River formation rises to 4,200 feet. It drops to about 2,700 feet in Roaring River Canyon and rises to 3,000 feet on the Mount Mitchell ridge (north side of Oak Grove Fork); it drops to 1,700 feet on the south side of Oak Grove Fork, from where it is lost under a confusion of andesite flows (figure 24). The low surface in the vicinity of Sandy River is in line with the projection of the Dalles syncline.

To the west of this fold are other folds and perhaps faulted structure. It suffices to say that all of these folds are nearly of equal height and have in gen-

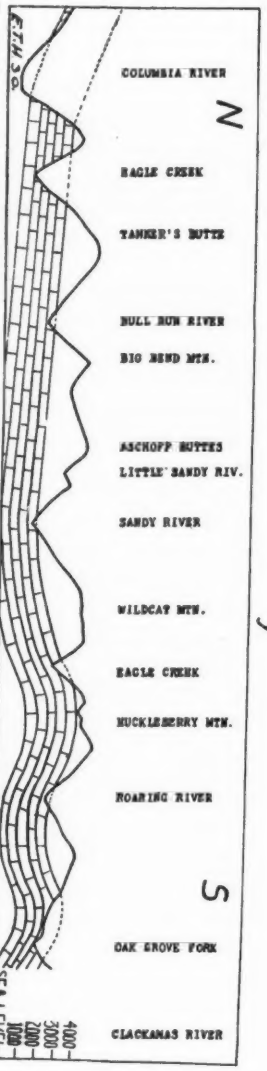

FIGURE 24.—*North-south Cross-Section of the Columbia River Formation from Columbia River Cascade Canyon to 10 Miles South*

The white portion is the Dalles and Cascade formations; the blocked portion is basalt. This section extends from due north of Mount Hood southward around its western side and illustrates the fact that Cascade Canyon of Columbia River has cut through a high portion of the Columbia River basalt formation. It also shows that if Columbia River had before accumulation of the Cascade formation, once followed the Dalles syncline to the south side of Mount Hood and then turned westward, it would have found a lowland in the vicinity of Sandy River, through which it could have escaped to the west.

eral a parallel strike. They all plunge to the southwest, and if the Ortley anticline did not exist, the other folds would have formed a series of obstacles to the course of Columbia River on its present site.

Maryhill Trough

The trough formed by the northern end of Shaniko surface and Columbia scarp is called the Maryhill trough. The trough is divided into two parts by the Klondike anticline. The eastern portion formerly opened only into the Umatilla basin, the western portion into the Dalles syncline. Maryhill trough, as already described, was broken by a mosaic of fault-blocks.

The trough never extended farther west than the Ortley fold as shown by the Columbia fault.

The Columbia River fault may end against the Lyle fault (figures 1 and 2) in the northwest corner of township 2 north, range 13 east. Columbia scarp ends just east of this point (west of section 21, township 2 north, range 13 east), perhaps owing to the fact that the fault passes into the river. The Lyle fault may be the result of the tendency to fault on the east side of the Ortley fold, which tendency was stopped in its early stages by the relief of strain because of the development of the Columbia River fault. If both meet beneath the river it is possible that the Columbia fault ended against the Lyle fault, and all tendency to fault farther west was taken up by movement in the Lyle fault.

Lyle fault is on the north side of Columbia River 3 miles east of Lyle (figure 12). The beds on the west side of this fault rise gently westward to form the crest of the Ortley anticline. Next to the fault the beds are almost horizontal; on the east side they are bent downward at an angle of 70 degrees west, beyond which the overturned beds readjust themselves and extend eastward as the unbroken east limb of the Ortley anticline to the Dalles syncline. Since the basalts occur on both sides of the Lyle fault and are very similar in character, it was impossible to determine the amount of movement in the fault. The beds in the fault-zone are broken into numerous small blocks which continue the general trend of the bedding. Between each fault-zone block there is much broken, shattered, sheared, and slickensided material. The fault-zone has been eroded into a gully which obscures many of its details. As far as can be determined the total movement in this fault is not more than 100 feet.

The strike of the Lyle fault is parallel with the strike of the Ortley anticline and like many other faults in this region it was formed on the steepest side of the fold. This fault, traced northward by topographic

methods, trends about north 60 degrees east, and probably extends across the Ortley anticline to the Warwick fault. Certain topographic features suggest that the Lyle fault extends from the south side of Columbia River for a distance of 1,000 feet.

A fault beneath Klickitat River is also a possibility. No projection of this fault to the south side of Columbia River by displacement of beds can be found. However, just east of Mayer Park the beds exhibit a crumple in the west limb of the Ortley fold with dips as high as 55 degrees. This strong dip to the west conforms to a down-dropped block on the west side of the Klickitat fault. North of Columbia River and on the east side of Klickitat River the beds at 2,000 feet elevation dip only 1 degree north, 45 degrees west; on the west side of Klickitat River the beds at an elevation of 800 feet dip 4 degrees south, 45 degrees west. The beds dipping northwestward from the crest of the Ortley fold must bend down very steeply or fault to the level of the almost horizontal beds on the west side of Klickitat River. No evidence of such a sharp monoclinal fold was found and it is not likely that the basalts would bend as much as would be required without faulting.

Klickitat River has a remarkably straight course, and cuts directly across the flank of the fold, an unusual relationship which can be best explained as due to a fault with a downthrow on the west side. This fault would be almost parallel with the Lyle fault and, if the Columbia fault follows Columbia River, would further serve to interrupt its further extension to the west.

In conclusion, we may say that the south branch of the Columbia River fault ends in the east limb of the Ortley fold.

Dalles Formation

The description, so far, has dealt with features determined by the Columbia River basalt. Lying on Shaniko and Coriba surfaces and in the Maryhill trough are later deposits. The Dalles formation is composed of stream-deposited gravels, muds, and pyroclastics separated by a few thin flows of lava. The materials of the formation were furnished by volcanoes in Cascade Mountains in Pleistocene or late Pliocene times. At times lava flowed over, buried, and sealed the stream deposits. The stream deposits (95 per cent) and lava flows (5 per cent) are known as the Dalles beds. When the lowlands near the volcanoes were filled, many streams carried the Dalles beds eastward almost to Deschutes River.

The Dalles formation is a lenticular mass which extends south from

The Dalles to a gap between Tygh Ridge and Cascade Mountains, and may extend much further south. It thins out towards Deschutes River on the east and towards the Cascade Mountains on the west, except in older lowlands cut in the underlying Columbia River formation. Thus, streams (Eight-Mile, Ramsey, and Fifteen-Mile creeks) which cut deep canyons show that it is very thick where the old Deschutes-West Columbia River valley is supposed to lie. In what we suspect to be the old Columbia River valley (the vicinity of Sandy valley near Rhododendron on the west side of the Cascade Mountains) we have great beds of sedimentary rocks and lava flows totaling 3,800 feet in thickness.

Arlington Formation

Adjacent to Columbia River, and lying on Shaniko surface, is the Arlington formation. It is composed of stream gravels and lake beds. In the gravels near Umatilla Pleistocene fossils have been found.

The Arlington formation is found in the Maryhill trough. It is found north of Columbia scarp only where its crest is low east of Roosevelt. Along Arlington Canyon, a name given to that portion of Columbia River Canyon east of the Ortley anticline, it occurs in a narrow belt adjacent to the canyon walls. West of Deschutes River the contemporaneous Dalles formation gradually thickens, becoming very thick at the foot of Cascade Mountains. Likewise, east of Deschutes River the Arlington formation increases in thickness until it is very thick in the vicinity of Arlington. Beginning about a mile east of Maryhill, residuals of Arlington beds are found occurring casually on the benches on the north side of Columbia River. On the south side a short distance east of Deschutes River, they form a continuous deposit. Wherever the beds occur they show a concordance on the two sides of the river. On the benches some of the beds have been eroded away, as shown by the fact that the benches emerge under the beds and form a brief or narrow platform contiguous to Arlington Canyon. The outer or river edge of the bench appears to have been swept clean of these beds. North and south of this narrow platform the Arlington formation occurs uneroded except by a few minor canyons, indicating that the removal has been by river erosion and not by upland erosion. The beds do not occur within Arlington Canyon.

The Arlington formation grades westward into the Dalles formation. Both were formed almost contemporaneously. The latter was deposited during upper Dalles time and for a short period thereafter.

Cascade Formation

The Cascade formation is composed almost entirely of lavas from Cascade Mountain volcanoes, representing the later liquid products of the same volcanoes that produced the pyroclastics of the Dalles formation. The Cascade formation, therefore, lies on the Dalles formation.

Intermittently between the stages of deposition of the heavy Dalles sedimentary beds there were periods during which lava eruptions covered a very large portion of this country, especially the area west of Deschutes

FIGURE 25.—*Photographic view looking North from Quinton to a Recent Lava Flow*

In the distance is the fault-scarp; The Burn is across the river on the right; in the foreground is the rough young lava flow which issued from the fault-zone at the west end of The Burn and once covered all the low area in the picture.

River. In the later stages of this particular accumulation of material, vulcanism became the dominant factor, and in our studies we divide the resulting formations into two portions: the lower, called the Dalles formation, which comprises all the lake beds and stream beds and intercalated lava flows; the upper section where lava flows predominate, called the Cascade formation, which comprises the entire series of flows that form Cascade Mountains and wherein sedimentary materials are almost nonexistent. The transition between the predominantly sedimentary Dalles formation and the predominantly lava Cascade formation is rather sharp and easily determinable. The Dalles formation may be traced up many valleys toward the Cascade Mountains, and in each valley the Dalles formation is clearly seen underlying the Cascade formation. Since no

disconformity exists we have, for the purpose of mapping, included the uppermost lava flow which spreads far to the east and caps Dalles sediments in the Dalles formation. The flows above the capping were not as extensive, as liquid, nor as thick as the flows in the Dalles formation.

The young lava flows that lie at the base of Columbia scarp are thought to have issued contemporaneously with Cascade lavas.

A feature characteristic of all these young lavas is that though their point of issuance and their pathway may be from a high bench, yet their largest distribution is always on the lowest mosaic blocks, which they cover and to a large extent conceal. The lowest mosaic blocks have acted as basins into which the lava flowed, filling them up to shore against all the surrounding walls formed by the other and higher standing mosaic blocks or benches. From the low basins the young lavas flowed up a short distance and down for a considerable distance along the canyon of the Columbia River (figure 25).

The lava flows on the lowland are well preserved, and where not washed by the river, have had only their included ashes and tuffs removed by erosion. This indicates that the river cut quickly through the lava, leaving the flows on either side uneroded. The removal of the soft parts of the flows left a mazy, pinnacled, and ragged surface. In a few places the lavas were plastered onto Columbia scarp where, because of the large lava boulders, they are preserved as pinnacles.

The source of the younger lava is obviously near the scarp, because at the base of the scarp the pinnacles become more prominent and higher, and at a number of places the pinnacled material can be seen lying against Columbia River basalt which dips definitely to the north—a true contact.

The composition of the highly scoriaceous matrix is very difficult to determine, but the solid nuggets that occur in it are all of an andesitic character and the abundant scoriaceous material, ashes, and the nuggets clearly point to a very young lava flow. The basic andesite is identical with that of the Cascade formation.

The pile of pyroclastics accumulated against the scarp face and, if high enough, on the Goldendale surface. After the pyroclastic, or explosive, stage had ended, then lavas, owing to the lava-static pressure, broke through the pyroclastic pile near its base, and some, owing to the excessive pressure from below and resistance to venting by the lava-soaked pyroclastic pile, have pushed up along the scarp-pyroclastic contact. This lava, working up the contact, froze to the scarp. Later, erosion removed most of the lean-to pyroclastic masses along that portion where,

on the lower mosaics, the river can sweep close to the fault-scarp. On the higher benches, Maryhill and Wishram, the pyroclastics have not as yet been completely removed and the lavas may be seen descending over their surface and emerging from their sides against the cliffs. Towal volcano is such a vent and is preserved from river erosion by the defending Goodnoe bench (figure 9 at *T*).

One volcano just west of Maryhill (figure 10 at *V*) was built as high as the scarp crest. The lavas lie on and in places fill small valleys in Arlington beds; also, the excellent preservation of the lavas and the fact that Columbia River has not completely cut through them shows these lavas to be Pleistocene or Recent in age.

Time Scale

Evidence has been given to show that the Columbia River fault cuts into the axis of the east limb of the Ortley anticline at an angle of 30 degrees and that the Warwick fault, in Goldendale surface, cuts into the axis at a larger angle. Also, evidence has been given to show that the Dalles syncline was faulted when it was only a minor fold and that since that time continued compression has folded the basalts south of the Columbia fault into a major syncline. Between the major (Dalles) and minor syncline is an abrupt change in dip and displacement of strike at the fault plane. The Columbia River fault, therefore, is younger than the folds, though it may have been formed during the later stages of folding.

The amount of erosion of Columbia scarp crest and folds also indicates that the scarp is young. Thus, the crests of all folds mentioned in this paper that approximate the same elevation as the scarp crest have been only slightly eroded; and the limbs and the intermediate synclines are well preserved. The scarp crest is preserved, and the scarp face in places preserves portions of the fault-plane.

The Columbia River formation was laid down in the Miocene, later folded, and still later faulted. After the faulting and before the deposition of the Arlington and Dalles formations a period of erosion intervened. In this area the amount of that erosion was just sufficient to dissect the crests of the higher folds, but was not prolonged or intense enough to destroy the original surface of Tygh ridge (3,000 feet), Gordon Ridge (2,500 feet), or smaller folds, or to remove the original lava crust from large areas of Shaniko surface.

On Shaniko surface against the fault-scarp and on the folds, now under the Cascade Mountains, were laid the Arlington, Dalles, and Cas-

cade formations. These Pleistocene formations are later than the faulting. Therefore, until more positive evidence is found, the writer proposes to date the folding as late Miocene, the faulting as early Pliocene, and the short erosional periods as late Pliocene.

The Dalles and Arlington formations are tentatively placed in early Pleistocene and the Cascade formation in middle Pleistocene.

Consequent Drainage due to Fault and Folds

General statement

Complete topographic and geologic mapping of north central Oregon has furnished no evidence of the drainage system existing on Shaniko, Goldendale, or Coriba surfaces prior to the Columbia fault. The records of drainage are Pliocene in age, and it was initiated by the tilting northward of Shaniko surface. John Day and Deschutes rivers and their main tributaries are strictly consequent on Shaniko surface south of the former boundaries of the Arlington and Dalles formations.

These streams are the product of the tilting of Shaniko surface by faulting. At no place along Columbia scarp are there evidences of streams which once crossed its crest previous to the faulting. Only at one place, north of Quinton opposite an old abandoned channel of John Day River, is a north side stream, Rock Creek, in line with a south side stream. Rock Creek, however, is clearly a stream that developed by headward erosion from Maryhill trough in Pliocene time. The scarp crest is well preserved except where it is cut through by streams such as Rock Creek, all of which are consequent to the scarp face and only a few have gained a northward obsequent extension beyond the scarp crest into Goldendale surface. Between these young notches in the crest, Goldendale surface extends to the very edge of the scarp crest. If the scarp were the result of river erosion it would be expected to show in places a curvature corresponding to that of the river. The river has not determined Columbia scarp, but the scarp, in conjunction with Shaniko surface, originally determined the Pliocene consequent course of Columbia River. The Pleistocene course has been determined by lake beds and by Columbia scarp. The earlier prefaulting drainage on Shaniko surface was so imperfect and shallow that it has left no traces. Faulting and tilting produced on it a consequent drainage coursing northward to the Maryhill trough.

It is not the purpose of this paper, nor indeed, do our investigations permit us, to make statements regarding the amount of water that was brought from the east into Maryhill trough after the faulting in Plio-

cene time. But whether the amount of water was large or small one fact is certain, namely, that a drainage basin was developed bounded by Columbia scarp on the north, the Ortley anticline on the west, and Shaniko surface on the south. This drainage basin was divided into two parts by the Klondike anticline. For instance, the courses of lower John Day and lower Deschutes rivers show a remarkable parallelism—both rivers flow north joining Columbia River almost at right angles, they show the same large curves in the same direction and in the same latitude, and both have tributaries of the dendritic type (figure 2). Their similar courses have resulted from a common structural surface. Their north courses were formed by following down the dip-slope of Shaniko surface, their large curves were in response to the swells and swales, and their dendritic tributaries were cut by eroding headward along the strike of the swells and swales.

John Day and Deschutes rivers took their waters northward into a depressed area or basin. The altitude of Maryhill trough immediately south of the present Columbia River is 1,900 feet at the crest of the Ortley anticline, 500 feet at The Dalles, 1,000 feet between Sherman and Arlington, and from Arlington gradually descends to 400 feet at Irrigon. Irrigon lies in the center of a structural basin.

JOHN DAY-EAST COLUMBIA RIVER

General statement.—Thus, water from John Day River and any water that may have come from the east met an adverse slope (the Klondike anticline) and may have formed a lake. (By East Columbia River we refer to that portion east of Umatilla, long or short, either integrated with all the tributaries it now has or a nonintegrated short Pliocene stream.) Such a lake would last only long enough for its waters to rise and spill over the Klondike anticline.

The Klondike anticline was developed, if not simultaneously with the production of the fault, at least so soon thereafter that for all practical purposes the fold was a barrier. There are two methods to explain how John Day River and East Columbia River crossed over Klondike anticline. The writer offers three theories based on these two methods:

Antecedent course.—A consequent stream at the base of Columbia scarp supplied with water by the Deschutes and John Day rivers and Alkali and Willow creeks, as well as other streams, flowed westward and continued to follow this course as an antecedent stream while the Klondike anticline was formed.

Against the antecedent stream theory, we find the following objections: the flat crest of the Klondike anticline is over 20 miles wide and

John Day River would of necessity have had to cut a deep canyon in the basalt in order that its waters, along with those of the Columbia, might be carried through this gap. Assuming that such a canyon was cut, then we should have to explain how John Day and Columbia rivers found their earlier canyons again and cleaned them out after the deposition of the Arlington formation. We should find superposed courses and abandoned canyons now buried with Arlington debris. These we do not find, and we may therefore eliminate this theory.

Superposition.—(*a*) John Day River flowing into the Columbia sent its waters eastward along the foot of Columbia scarp where they accumulated in a lake. (The large lake, so formed, we may call "Umatilla Lake.") The larger quantity of water accumulating in this lake was not, however, supplied by streams of Shaniko surface, but rather came from the east by "Upper Columbia River." The sediments supplied to this lake (either silt or gravels) would have come mainly from the east; hence the current was largely from the east and the silts were carried to the distal or western end of the lake, whereas the gravels were at first deposited in the eastern end of the lake and gradually as the lake became filled were spread farther westward. When the level of the lake reached about 1,000 feet elevation it superposed the Columbia River across the Klondike fold, and as this fold was cut down, permitted the level of the lake to recede and the gravels to spread farther westward until finally they were deposited at the far end on the lake beds.

Superposition by Umatilla Lake could not have taken place unless the Arlington formation is older than the Dalles formation and at an early date superposed John Day-East Columbia River over the Klondike anticline. This hypothesis would explain the meandering of John Day River, but would not explain the meandering of Deschutes River. To explain the latter we require the Dalles formation. The Dalles formation was deposited to a level of 1,900 feet and we can trace it as far east as Deschutes River. It is evident that if the Dalles formation had been deposited in Columbia River canyon, it would have caused a damming and produced a deposition of additional beds on top of the Arlington formation because of sediments brought down by Columbia River. These later sediments we do not find; on the contrary, we find that the Dalles and Arlington formations were deposited contemporaneously. The deposits laid down in the Arlington area and those laid down in the Dalles area grade one into the other and are of the same age.

(*b*) Only one theory is left—the John Day-East Columbia River system was united with the Deschutes-West Columbia River at a later date

owing to the Dalles and Arlington formations. The method of union is discussed below under the heading "Diverted Columbia River" (page 976).

John Day-East Columbia River previously carried its water to Umatilla basin, probably in the Pliocene. The consequent Pliocene John Day River turned eastward at a point 8 miles south of Columbia River (where it was deflected by the Klondike anticline), flowed northeastward and entered East Columbia River by way of Willow Creek, over 30 miles east of its present confluence with Columbia River. This old channel is now partially buried by the Arlington formation. In the Umatilla basin, there is no evidence of a Pliocene lake. The gravels and lake beds in it are Pleistocene in age and their composition and distribution point to a source toward the east. The absence of Pliocene deposits indicates that the East Columbia system was not at that time linked up and that only minor streams contributed to the Umatilla basin.

The amount of water at this time probably was not considerable. There were no Cascade Mountains to the west to serve as rain catchers or to furnish an extensive supply of water to their slope and to the Deschutes River.

The crests of the folds, now buried by the Cascade formation, are not more than 1,000 to 1,500 feet higher than Shaniko surface. Where the large folds plunge southwest their crests are not high enough to have caught much water, and the water obtained was probably discharged down their southwest plunging structural valleys. This statement, of course, is based upon the more or less assumed premise that little or no folding has taken place since that time, an assumption the writer believes can be sustained. True, it is quite possible that the Ochoco and Umatilla mountains southeast of John Day River received as much rainfall as at the present time. This, if true, would explain the much more elaborate development of the tributary system of the John Day River than of the system of Deschutes River.

DESCHUTES-WEST COLUMBIA RIVER

As stated earlier there were at that time two streams—two Columbia Rivers. The John Day-East Columbia River carried its waters eastward to some basin of accumulation or evaporation, perhaps the Umatilla basin. Deschutes River flowed north down Shaniko slope, turned west and flowed down the slant of the Klondike anticline in Maryhill trough to the Dalles syncline (figure 2). Beyond stood the Ortley anticline, the east limb of which begins just at the point where Columbia River

makes the abrupt sharp bend to the north. This anticline strikes south 42 degrees west across Columbia River; it is an almost uneroded fold and plunges to the southwest.

The Ortley fold and Columbia scarp formed a continuous wall which, if older than Columbia River, prevented the river from crossing the Cascade Mountains on its present course. At this point where the Cascade and Dalles formations overlap the pitching anticline and determine a col, the col had an elevation of 1,900 feet. At The Dalles, Shaniko surface had, then, an elevation of 500 feet,[5] whereas the crest of the fold had an elevation of 1,900 feet, making a difference of 1,400 feet. It is clearly evident that the river did not climb over this wall.

Columbia River not an antecedent Stream

Previous writers have assumed that Columbia River followed an antecedent course through the Cascade Mountains. If this theory be true, then the Ortley anticline must have been slowly upraised while Columbia River maintained its course. The writer offers evidence in this paper that the Ortley anticline is older than Columbia scarp, and the latter is older than Columbia River. Hence Columbia River is younger than Ortley, the first major fold that the Pleistocene river crosses.

Goldendale surface, extending northward from the scarp crest, is well preserved east of Stacker Mountain except where modified by local faults. To the west of Stacker Mountain, the Warwick fault splits off from the Columbia fault, continues west, and clearly faults the north limb of the Ortley anticline. South of the Warwick fault the Columbia fault also cuts into the southeast limb of the Ortley anticline. Thus, it is evident that the Ortley anticline was in existence previous to the Columbia fault, and Columbia River is of later age and not earlier or antecedent. This conclusion is the foundation upon which is laid the theory offered in this paper, and it is considered by the writer to be well established.

Further evidence against the antecedent course of Columbia River may be added:

(1) If the Ortley anticline is younger than the fault there are two coincidences to explain: (*a*) that the Columbia fault cuts into only a part of the east limb of the Ortley fold, or (*b*) that the folding was just enough to bring the beds on the south side of Columbia River in line

[5] The present elevation at Chenoweth Creek is 200 feet, probably because of pre-meander erosion, which amounted to 300 feet at the maximum and usually was less than 100 feet.

with those on the north side. The beds on the north side of Columbia River can be traced continuously into the west flank of the Dalles syncline.

(2) The narrowest constriction along the entire course of Columbia River is just at the point where it cuts through this fold. An ancient stream older than the fold should by this time have widened the first water gap unless later deformations have created a new gap. The water gap is a simple one showing no sign of an earlier stage of erosion, and the fold here is more simple—not less—than western folds with larger water gaps.

(3) The southwestward course of the river to The Dalles changes to a northward course in a 90-degree turn just at the point where the axis of the Dalles syncline is crossed by the river. This turn is required under a new consequent course, but would be a strange anomaly for an antecedent stream.

Before the burial of the westward continuation of Shaniko surface under the Dalles and Cascade formations, the trough of the Dalles syncline, practically at present river-level, must have served as the course of Deschutes-West Columbia River. It is significant, in this connection, that the apex of the bend of the river, at The Dalles, coincides with the axis of the Dalles syncline. Here Columbia River turns abruptly north in a course cut in the east limb of the Ortley anticline. If the river course east of the Dalles synclinal axis were projected it would lie in the axis of the syncline.

(4) The antecedent theory fails to explain the fact that entrenched meanders occur in only a part of Deschutes and John Day rivers. The rising folds might have slowed the current and brought about aggradation, and on floodplains so aggraded Columbia and its tributaries would have meandered. Acceleration of the current and resultant entrenchment would, however, have produced entrenched meanders in Columbia Canyon as well as in the canyons of its tributaries.

(5) The distribution of later formations is in harmony with the well supported inference that Columbia River did not flow across this fold, but followed a course to the southwest.

(6) If the river had maintained its course across the Ortley anticline then it must also have maintained its course across other anticlines farther west. But to the west in that portion of the Cascade Mountains along the site of the present Columbia River there are Pleistocene intrusive igneous rocks as well as later deposits which would have prevented such action; this will be discussed in a later paper.

(7) The paleotopography of the Columbia River formation as determined by the deformation of its initially nearly level surface is also proof that Pliocene Columbia River did not follow its present course.

(8) As described above the distribution of the Dalles formation is also witness of the former course of our buried Pliocene river.

The total evidence is neither large in amount nor conclusive, but such as it is, it points to the course or outlet of the old Deschutes-West Columbia River down the Dalles syncline through some path south of Mount Hood and westward.

Damming of Deschutes-West Columbia River

The probable former course of Columbia River in the Dalles syncline was blocked by the Dalles and Cascade formations. Volcanoes south and north of the present course of Columbia River furnished the debris of the Dalles formation and the lavas of Cascade formation. The two formations buried, in the Cascade Mountains, the preexisting surface on which Deschutes-West Columbia River flowed. Both formations were laid down with initial dips in the same direction as the surface on which they were deposited and in many places with a greater dip than that of the underlying formations. The dips of stream deposits and lava flows were determined by the slope on which they were laid. Deposited from sources north and south of the present course of Columbia River, they left a trough along its present course.

The writer will not in this paper present his evidence in support of the theory that Columbia River was placed during the Pleistocene in a new course across the Cascade Mountains. Evidence will be presented here against only the antecedent theory, and in support of superposition on the Ortley anticline.

Deschutes-West Columbia River, following its course down the Dalles syncline and westward to the Pacific Ocean, was dammed by ejectamenta from many volcanoes and particularly from those in the vicinity of Mount Hood. The ejectamenta were carried by streams into all the lowlands, including the Deschutes-West Columbia River valley, and laid down as stream beds.

The volcanic dam so formed was higher than the col on the pitching Ortley anticline and that col was higher than any part of the boundary of Maryhill trough. The Dalles formation dammed Deschutes-West Columbia River and formed a lake as far east as Umatilla basin, to which we give the name "Condon Lake" after an early Oregon geologist. Condon Lake was backed up so that it extended across the anticlinal axis

of the Klondike fold at an elevation of over 1,000 feet as shown by the extension of lake beds eastward. So dammed, the river and its tributaries lost their transporting power. Upper Deschutes River must have received directly great supplies of pyroclastics from the Cascade Mountains and hence rapidly aggraded. The John Day-East Columbia River was affected in so far as winds carried pyroclastic material into its drainage system.

In the lake was accumulated, east of Deschutes River, the Arlington formation. This formation is composed of stream gravels, which lie at the bottom and top and become thicker to the east, so that the two gravel beds coalesce east of Willow Creek. Between the gravel beds lie lake beds. The top gravel bed, now much eroded, lies on the lake beds and can be traced westward along the walls of the present canyon of Columbia River. Hence the top gravels must have been deposited after Columbia River had been diverted west in its new course. Arlington stream gravels form beds from 100 to 150 feet thick in the vicinity of John Day River, but become thicker, as traced eastward, and a short distance east of Willow Creek replace entirely the underlying silt beds. Stream gravels occur on both sides of Columbia River and have been traced east beyond Umatilla. Thus, the lake beds are older than the top gravel beds.

The lake beds occur east of John Day River as far east as a few miles beyond Willow Creek, and on both sides of Columbia River, and extend to the very brink of the Arlington Canyon.

Arlington beds were deposited in Condon Lake up to 1,900 feet elevation, though above 1,650 feet they were very thin and have since been mostly washed away. They grade into the Dalles formation on the west, abut against Columbia scarp on the north, extend 10 to 15 miles south (approximately to Willamette base line), and have been traced as far east as Umatilla and may extend much farther east.

Additional proof of Condon Lake, or at least of a baselevel for alluvial fans sloping down from Columbia scarp, is found along the north side of Arlington Canyon. The profiles of the alluvial fans are all concordant and their projected slope points to a level at about 1,400 feet elevation. The bases of the fans have been truncated and the planes of truncation also are concordant. The fans represent alluvial fans deposited in Condon Lake, which, since the disappearance of the lake, have been left suspended. The current of the integrated Pleistocene Columbia River flowing at their bases has truncated them.

Certain it is that the Dalles formation was piled higher than 1,900 feet both across the Cascade Mountains and on its east slope. West of the

Ortley anticline the Dalles formation occurs in north-south elongated patches. These patches lie on surfaces, some structural and others erosional, which probably represent valleys that formerly opened out to the southwest. Thus, in the vicinity of Eagle Creek, 30 miles west of the Ortley fold, there was once a stream coming from the north, flowing south across the Pleistocene course of the Columbia River, and thence southwestward towards some other older stream whose valley is now buried. The above valleys were filled up to the level of 1,900 feet. Erosional remnants of the Dalles formation still linger, especially where protected by a capping of later Cascade formation andesites, on the Pleistocene crests of folds. On Seven-Mile Hill, 12 miles west of Ortley, they lie on a fold (Bingen). The water, finally reaching 1,900 feet elevation, spilled

FIGURE 26.—*Sketch looking East through Canyon cut in the Ortley Fold*
The east limb of the Ortley fold can be seen extending eastward to form the Dalles syncline in which lies, on the right (south), the Dalles formation.

across the small col at Ortley and furnished an outlet to Condon Lake (figures 13 and 26).

DIVERTED COLUMBIA RIVER

Condon Lake, bounded on the north by Columbia scarp, on the west by the Ortley fold, on the southwest by the Dalles formation, and on the south by the 1,900-foot contour of Shaniko surface, was raised high enough to cross the Ortley anticline. It spilled over, not on basalt of the Ortley anticline, but over a thin bed of the Dalles formation. Just west of the crest of the Ortley anticline on the south side of Columbia River are several small patches of the Dalles formation. A mile south of the patches, the Dalles formation forms a large uneroded area. Between the small patches abandoned stream channels are clearly shown. These patches were not elevated to the present position by folding. This is proved by their generally horizontal position, or if inclined, by their initial dip of 5 degrees, whereas on the Columbia River formation they lie with a dip of 2 degrees. The top of these patches is above the level of the basalt. On the north side of Cascade canyon are smaller patches of the Dalles formation plastered onto the slope of the Ortley fold. Here Condon Lake flowed out over this thin layer of the Dalles formation and recreated Pleistocene Columbia River. The rapidity with which

Columbia River cut down through the Dalles beds and was locally superposed on Columbia River basalt is impressively shown by the nearness of the Dalles beds to the brink of the first 25 miles of Cascade Canyon.

Before discussing the consequent course of Columbia River across Cascade Mountains and its later superposition through the Dalles beds onto the underlying Columbia River basalt folds we must refer again to the uppermost gravels of the Arlington formation.

If, as postulated in an earlier part of this paper, John Day River had flowed eastward it would have carried light silt into Umatilla basin. But it did not do this; on the contrary some river, probably East Columbia River or a lake current, flowed westward and deposited the silt at the distal or western end of the lake and the heavy gravels at the proximal or eastern end of the lake. Then, as the waters were drained, a widely swinging stream deposited thick beds of gravel over the drained lake beds.

Hence the gravels must have been brought from the east, indicating that at the last Pleistocene stage of Condon Lake a large supply of water was brought from the east. The writer does not know the source of these gravels, but their volume, hardness, freshness, and well waterworn condition indicate a long journey in a large river. Perhaps they are proof of the linking up of the rivers of Shaniko surface with those of eastern Washington, Oregon, and Idaho into a Columbia River system.

The integrated Pleistocene (including John Day-East Columbia River) spread gravels westward after Ortley gap was cut down as low as the lowest part of Condon Lake bed. The gravels were spread in Cascade Canyon on the Dalles and Columbia River formations. The gravels were spread, however, before the deposition of the Cascade formation. Therefore, in Cascade Canyon the gravels mark the dividing surface between the Dalles and Cascade formations. Some of the Cascade lavas reached or crossed the line, later to be followed by the new Pleistocene consequent integrated Columbia River. The single flows were in the main very thin, but in places a succession of flows 1,000 to 1,500 feet thick occurs. Such lava flows determined the consequent course of Columbia River. Like the Dalles formation, the beds of the Cascade formation show only initial dips, and are still at the elevations at which they were originally formed. Their severed ends lie exactly opposite each other on the brink of Cascade Canyon of Columbia River. Along with the Dalles beds they demonstrate the development of Columbia River consequent on the Arlington, Dalles, and Cascade beds and its final superposed course into Columbia River basalt.

Effects of Diversion

MEANDERS

The Dalles formation at the beginning formed a temporary baselevel for Deschutes-West Columbia River and later for Condon Lake at the col above the Ortley anticline; still later Condon Lake formed a temporary baselevel at about 1,900-foot contour, and finally, Columbia River cut down into the Ortley anticline and then assumed its course over the lake beds and drained Condon Lake, forming a temporary baselevel that continues to the present time. These various baselevels caused the streams to establish low gradients that, combined with the large amount of pyroclastics carried to them by wind or washed into them from Shaniko surface, produced an aggradational stage in the streams.

The valleys, so aggraded, were not more than 100 to 150 feet deep, as shown by the older valleys south of the meander belts in which the younger ones have been incised. On the flood plain formed in and across such shallow valleys the John Day and Deschutes rivers meandered.

The meanders were not produced on Shaniko surface when it first carried the consequent streams to Maryhill trough, because if that were true the stream with lowest gradient—Columbia—and the Pliocene streams in Maryhill trough, should show the best meanders; also, the lower portions of John Day and Deschutes rivers should have very good meanders. Columbia and lower John Day and Deschutes rivers have no meanders; the meanders begin 12 to 15 miles south of Columbia at about the line where the 1,700-foot contour crosses Shaniko surface, and continue northward to within a few miles of the Pleistocene Columbia River.

Further evidence will be given below to show that damming, aggrading, consequent course, and superposition give the only possible explanation of the meandering.

CANYON CUTTING

Inasmuch as the slope of the rivers on Shaniko surface appears to have been too steep for the formation of meanders we must infer that the meanders are strong evidence of aggradation due to temporary baselevels. This conclusion is supported by other evidence as well, proving the canyons of Columbia, John Day, and Deschutes rivers to be of later date than the Dalles, Arlington, and Cascade formations. Thus, when the level of Condon Lake was raised sufficiently to spill over the col on the Dalles beds lying on the Ortley anticline, the spilled water on the far side of the gap was provided with a steep gradient, the elevation dropping

from about 1,900 to zero at some point east of the mouth of Columbia River. The new Pleistocene Columbia River, following its integrated consequent course westward across the highlands of the Cascade Mountains and falling rapidly to their western base, was abundantly supplied with water by all the streams contributing to Condon Lake and by the lake itself; and later, when the level had been lowered, into the river came the unconsolidated debris that had accumulated in the drainage basin.

Only after an examination of the great accumulation of the Dalles formation can the reader properly appreciate the tremendous supply of material stored up. This debris varies in composition from boulders 10 feet in diameter to fine volcanic sand—all fresh and unconsolidated. Not only the stored materials were available, but in the early stages of cutting the canyon tributary streams from the Cascade Mountains steadily brought in a new supply from the active volcanoes and glaciers and continued to do so until a very recent date. The supply of large, fresh, and loose cutting tools was especially abundant on the east side of the Cascade Mountains. The new course of Pleistocene Columbia River was shorter than the former Pliocene course of Deschutes-West Columbia River. Also, as suggested by the gravels in the Arlington formation, the new Columbia River was probably linked up with other streams in eastern Oregon, Washington, and Idaho.

The abundant supply of tools, the large supply of water, and the steep gradient no doubt caused rapid cutting. The cutting, of course, was retrogressive and when the canyon had been cut down from 1,900 feet Condon lake was completely drained. It was after this down-cutting that the gravels of the Arlington formation were spread westward. Previous to this, however, the distribution of lake beds and gravel beds tell of an unfilled area—Umatilla basin—in which a lake lingered, here called Umatilla Lake. The draining of Umatilla Lake and the shifting of John Day River has left two abandoned channels, one at Quinton, and one 6 miles west of Quinton. Each of these outlets is deeper than the one west. The different positions of the outlets of the John Day River can only be explained by superposition, and they prove that the stream developed its present course after it had been superposed on the Arlington formation. Thus the shrinkage of Umatilla Lake was so rapid at its first two outlets that the John Day River did not entrench into the basalt, but it did so in its last entry. If this stream possessed a previous canyon earlier than this date then it is strange that somewhere along its course we do not find evidence of its old channel. If John Day River canyon is pre-

meander in age and if its canyon had been filled up with silt, then in cutting down through the Arlington formation it would be unreasonable to expect the stream to blindly discover its old channel and clean it out. Instead, we find that the stream occupies for the first time its present canyon. This canyon is superposed onto the east limb and crest of the Klondike anticline.

Fifteen-Mile Creek, just west of Deschutes River, flowing eastward down a steep alluvial slope and hence heavily laden, was first diverted toward Condon Lake by its own deposits formed on the flat lake beds and later formed a meandering Yazoo type of entry into Condon Lake. It turned parallel to the master stream for 10 miles before joining it. Two of its temporary entry ways are preserved, but it has held the third long enough to entrench into the basalt. The peculiar set of turns of Fifteen-Mile Creek, which are parallel with all the turns of Deschutes and Columbia rivers, is evidence of a superposed stream.

The movement of the south shoreline of Condon Lake was always to the north, hence Deschutes River followed straight to the north, creating no meanders in its lower course. If the Arlington Canyon of Columbia River was cut before the deposition of the Dalles and Arlington formations and these deposits finally dammed the canyon and caused the Columbia River to aggrade, obliterating all of its canyon as far east as Willow Creek, we should expect to find some evidence thereof. Columbia River in cutting down through these beds should have been superposed into new canyons in some places. Filled or cleaned out abandoned side valleys, unoccupied by a stream and off to one side of the present canyon, do not exist. None of the usual features of a stream which has been displaced from its former course and superposed in some new places are to be found along Columbia River. The entire history shows that the present canyon of Columbia River and the present canyons of John Day and Deschutes rivers are being occupied for the first time in the history of these streams, and that these canyons have been formed by streams superposed upon a former surface.

In many places these streams cut indifferently across the structure; thus, the John Day has been superposed northwestward up the limb of the Klondike fold. Fifteen-Mile Creek has been superposed westward up the limb of the Dalles syncline, and Columbia River lies athwart the steep Ortley fold.

All deposits younger than the Columbia River formation lie horizontal or with small initial dips and extend to the very edge of the young canyon. They have been swept away only from the adjacent platform above

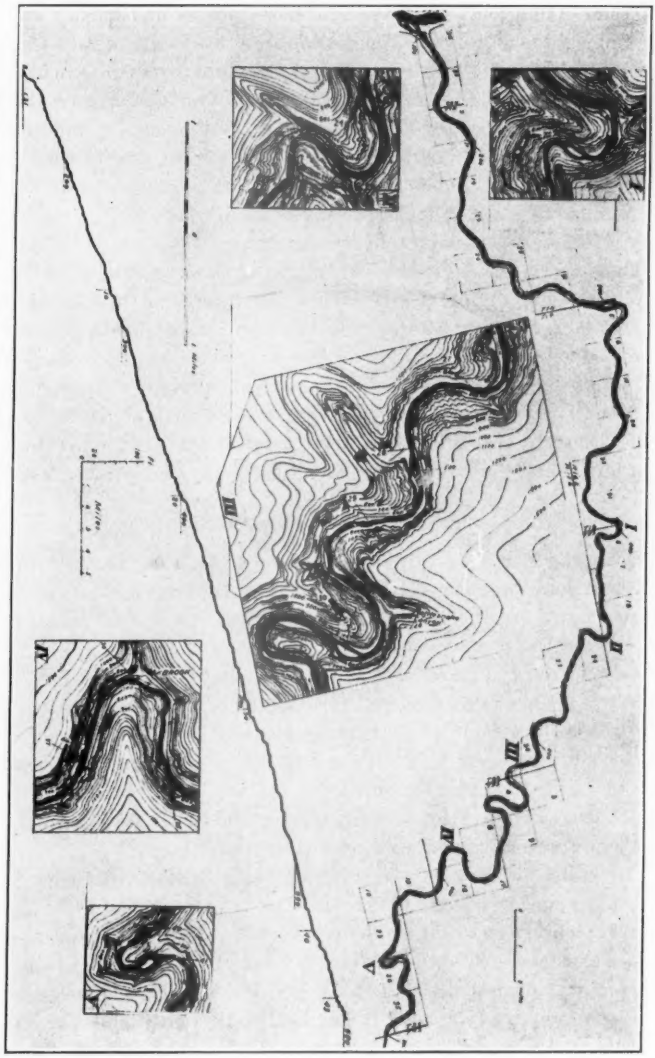

FIGURE 27.—*Present Profile, entrenched meander Belt, and Details of five Meanders of Deschutes River*
Topography by Hodge.

the canyon. All this signifies that Columbia River, flowing over the Dalles or Arlington beds, received a new impetus and quickly cut down to the hard basalt below. The erosion due to velocity was so great that it did not have time to develop meanders before it was entrenched in the basalt formation. The entrenchment of the river was so good that after a short time none of its water reached above the canyon walls to sweep away the Dalles and Arlington beds. The stream once within its canyon has never had a chance to clean away these upland beds and their erosion has been due only to the lateral wash, which in this region is not very intensive because of the light rainfall.

The final evidences of the youthfulness of Cascade Canyon of Columbia River are the hanging valleys. These occur only in the Cascade Mountains, where the great erosive work has been concentrated. They can not be explained under a theory of antecedent streams, but they offer excellent support to the hypothesis of a young stream rapidly cutting down after rejuvenation by a new consequent course, and then superposition. The tributaries are larger than the tributaries of the undiverted John Day, Deschutes, and Columbia rivers which enter at Condon Lake levels.

ENTRENCHED MEANDERS

Beginning 6 miles south and extending to 30 miles south of Columbia River and south of township 1 north, north of township 4 south, Deschutes and John Day canyons show excellent entrenched meanders (figures 27 and 28).

Farther south, that is, beyond Condon Lake, it is shown that the Canyons are not entrenched meanders. Columbia River shows no entrenched meanders. The depth to which John Day and Deschutes rivers have been entrenched is concordant with the depth of the Arlington Canyon of Columbia River. Shaniko surface slopes northward 48 feet to the mile, which is a slope too steep to start or permit meandering. The entrenched canyons are of course even younger than the meanders.

Assuming for the sake of discussion that either before or after faulting, John Day and Deschutes rivers meandered; then we can find no evidence of rejuvenation by uplift or increased supply of water. Instead of uplift, Shaniko surface suffered depression from down-faulting which carried its northern edge down to 1,000 or 500 feet elevation above sealevel (or perhaps even less), a level it has held with remarkable persistency as shown by the undeformed Arlington, Dalles, and Cascade formations. (The deformed Mascall (Upper Miocene) and Rattlesnake (Pliocene) formations were warped previous to or at the time of faulting.)

FIGURE 28.—*Present Profile, entrenched meander Belt, and Details of twelve Meanders of John Day River*
Topography by Hodge.

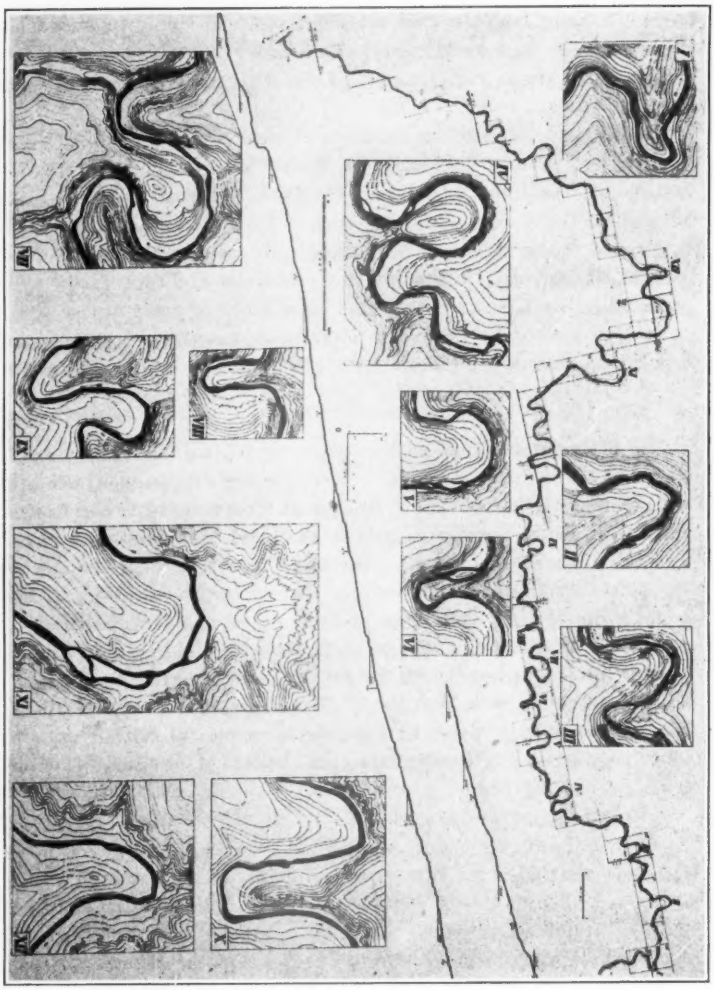

FIGURE 28.—*Present Profile, entrenched meander Belt, and Details of twelve Meanders of John Day River*
Topography by Hodge.

An increased rainfall can only be postulated on the basis of elevations increased sufficiently to capture more rainfall. As stated above, Shaniko surface has not been elevated but depressed. The only increased elevations are in the Cascade Mountains and these are due to volcanic accumulations; they are of the same age as the Arlington, Dalles, and Cascade formations.

Finally, as proof that the meanders of these two rivers require a special explanation, attention is called to their character north of their last meanders. Deschutes and John Day rivers north of township 1 north, as well as the Columbia River, occupy their present canyons for the first time. Their walls have been thoroughly inspected and nowhere show abandoned canyons. Since all three canyons are concordant and all occupied for the first time, then they must all be of postmeander age.

Erosion worked up Columbia River to its tributary streams, where it caught and preserved all meanders of the John Day and Deschutes rivers.

Conclusion

The evidence presented in this paper supports a new theory as to the origin of lower Columbia River. The new explanation contrasts sharply with the old. The river is not an ancient stream that has maintained an antecedent course over large folds in the basalt and across the many obstructions placed in its path. On the contrary, it is a young stream, vigorously carving a new canyon in a recently acquired course. Its history is not a simple one. Its earlier predecessors were several in number and consequent on surfaces developed by faulting and folding. Later dammed, ponded, and integrated with its eastern tributaries, it resumed a new consequent course at a high level. The Pleistocene Columbia River has in a relatively short time cut a deep and wonderful canyon, superposed into the great folds of basalt, across the Cascade Mountains.

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EXCEPTIONAL MORAINELIKE DEPOSITS IN OREGON[1]

BY EDWIN T. HODGE

(Read before the Pacific Coast Section of the Society, at Pasadena, California, March 6, 1931)

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INTRODUCTION

Exceptional morainelike deposits occur south of Columbia River between Willow Creek and John Day River and near Chenoweth Creek southwest of The Dalles (figure 1). The deposits are so peculiar in their occurrence and form and have such an important relationship in regard to the stream pattern of Columbia River and its tributaries that they deserve special attention. They were discovered in 1927, mapped in detail in 1930, and are herein described for the first time.

The exceptional features of these deposits are their location and preservation. Geologists to whom they have been shown declare that

[1] Manuscript handed to the Secretary of the Pacific Coast Section, Geological Society of America, June 23, 1931. Manuscript received by the Secretary of the Society July 2, 1931.

they are true moraines or at least show morainelike topography. Accepting this conclusion, certain aspects of their location become difficult to explain, for the deposits are (1) almost on the brink of the great Columbia River canyon; (2) far removed from any possible source of mountain glaciers that might have deposited them; (3) surrounded by an area which shows no evidence of ever having been covered by glaciers; (4) much more than 100 miles from the well-known and generally accepted southern limit of continental glaciation in northwestern America; (5) located in a most exposed position where their rapid destruction should have been a matter of natural course.

FIGURE 1. — *Location Map of Area*

Columbia River forms the political boundary between Washington and Oregon. Morainelike deposits lie close to Columbia River within the rectangles. The westernmost, in the vicinity of The Dalles, is called the Chenoweth area, and the central one, in the vicinity of Arlington, is called the Arlington area.

A study of these deposits has led the writer to the conclusion that their position and origin has an important bearing upon certain problems of northwestern American geology—problems of long standing and some of them the subject of frequent and often vehement discussion. Two areas bear these deposits: Arlington area, adjacent to the Columbia River between Willow Creek and John Day River; and Chenoweth area, up Chenoweth Valley on the east flank of the easternmost fold of the Cascade Mountains (Ortley fold). The two areas complement each other in the evidence offered. We shall first discuss the Arlington area.

ARLINGTON AREA

OCCURRENCE

These deposits occur south of Arlington [2] in four small patches and one large patch, and cover a total area of 40 square miles (figure 2, south of *A*). The separated areas are considered remnants of a once larger and more continuous area. The belt in which they occur is 5 miles wide and 18 miles long: in the northeast portion they lie within 1 mile of Columbia River (*CR*), and in the west 4 miles from it. In the northeast their outer boundary is 7 miles from the river, in the west 9 miles.

[2] In township 3 north, ranges 21 and 22 east; township 2 north, ranges 20, 21 and 22 east; they are less well developed in township 2 north, range 19 east, and township 1 north, ranges 19 and 20 east.

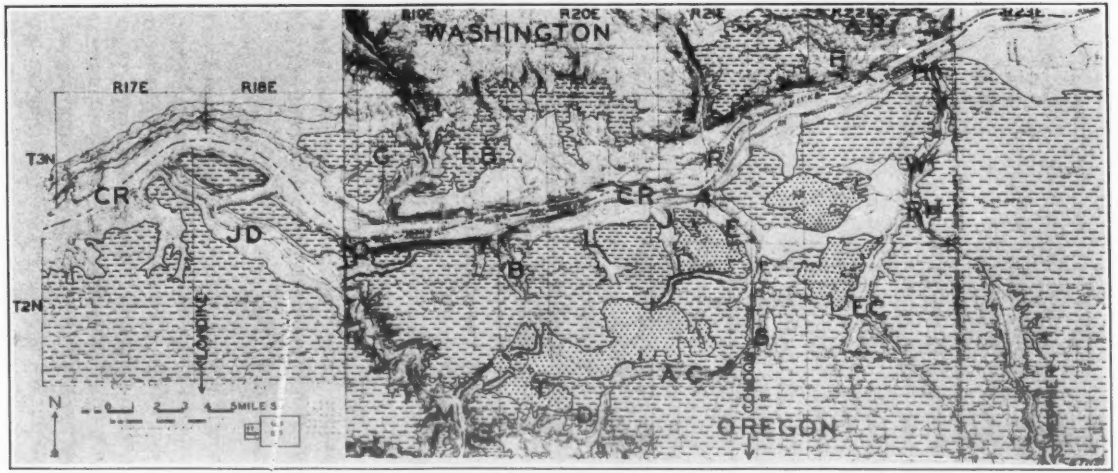

FIGURE 2.—*Topographic and geologic Map of the Arlington Area*

Stippled area, morainelike area; lined area, Arlington formation; unmarked area, Columbia River basalt; hashured channels and pockets were cut after the deposition of part of the morainelike deposit. All lie on north-dipping Columbia River basalt surface, which terminates abruptly in a fault-scarp on the north side. Beginning at the left side and reading down in ranges the symbols are: *CR*, Columbia River; Klondike, the axis of the Klondike anticline in Columbia River basalt, now buried by the Arlington bed except where reexposed in the canyons of John Day and Columbia rivers; *JD*, John Day River; *G*, Goodnoe flat; *TB*, The Burn, part of the basalt dip-slope surface now separated by Columbia River; *Q*, Quinton, below an abandoned channel of Columbia River; *M*, McDonald, at the foot of discharge channels that crossed the older deposits. Just to the south of McDonald, John Day River turned eastward and followed a channel, now only partially reexcavated, northeastward previous to the deposition of the Arlington formation. *B*, Blalock Canyon; *L*, Lang Canyon, post-Arlington canyon cut through these beds and tributary to Columbia River; *T*, Turner Butte, a pre-Arlington basalt island almost completely surrounded by morainelike deposits; *D*, Diamond Butte, from which a deposit takes its name; *R*, Roosevelt; D-M, Rock Creek; *A*, Arlington, from which this deposit takes its name; *E*, Eddy, on Alkali Canyon, from which the small deposit on the west takes its name; *S*, Shutler, a post-Arlington canyon that has cut into the old valley of John Day River by working headward; *J*, Jones Canyon, a post-Arlington canyon like Blalock and Lang; *AC*, Alkali Creek, an abandoned stream course which once served as a discharge channel for waters going around the morainelike deposit and which in part forms the present course of John Day River; *AR*, Alder Ridge, a part of the fault-scarp partially covered by lake beds of Condon Lake stage, whose waters covered all of this region; *H*, Heppner Junction, at the mouth of Willow Creek and the former mouth of John Day River; *W*, Willow Creek; *RH*, Rhea, from which the small deposit to the west takes its name, at the mouth of Eight-Mile Creek, into Willow Creek and part of the former course of John Day River. Note that the basalt has been laid bare to the west of Rhea. *EC*, Eight-Mile Creek, from which the deposit to the northwest takes its name, and part of the old canyon of Columbia River. Topography in ranges 17 and 18 by Hodge, the rest by the U. S. Geological Survey.

No deposits occur on the north side of Columbia River. Their absence on the north side of the river east of Roosevelt (*R*) might be explained as due to the steepness of the escarpment, but such an explanation would not suffice because no deposits occur on a large, flat, upland area to the west, which is equally as favorable as the south side for the reception and preservation of the deposits. They are found, nevertheless, only on the south side of Columbia River, where they border the river but at no place approach its canyon wall nearer than 1 mile.

ELEVATION AND TOPOGRAPHY

The lower contact of the deposits with the underlying formations rise higher the farther west it is traced, ascending from 650 to 1,100 feet. Furthermore, the upper contact of the morainelike deposits with the island areas which project through it also rise from 900 to 1,100 feet from east to west. The Diamond deposit (*D*) stands at the highest elevation, and is the largest and best preserved. Its maximum height is not at its western end, but about two-thirds of the way towards that end.

Most of these deposits occur at an elevation above 750 feet, although adjacent to Eight-Mile Creek (*EC*) they are as low as 550 feet. Hills 953, 906, and 956 feet in height are islands of Arlington beds protruding through the morainelike material, with an upper contact at 900 feet. West of Alkali Canyon (*AC*) is the Eddy area (*E*) which lies on older formations at 700 feet on the east, 850 feet on the south, 750 feet at the top of Jones Canyon (*JC*), and on the north side against the high land mass southwest of Arlington at 900 feet. The Diamond area is due north of Diamond Butte (*D*) and its eastern end has a lower contact at 1,050 feet. South of Lang Canyon (*L*) the contact is at 1,100 feet, descending to 1,050 feet at the head of Blalock Canyon (*B*) and still further to 950 feet at the extreme northwest. Buttes that protrude through the deposits emerge at 1,050 feet in the extreme east and west—Turner Butte (*T*).

The greatest difference in elevation between the top and bottom contacts is 550 feet (between 1,100 and 550 feet). The lowest deposit is near the southeast end of the Eight-Mile Canyon (*EC*) area, and the highest along the center of the Diamond area (*D*). This great difference, however, is not noticeable to the observer walking over the area. He does observe that, against the mendips and defendant masses of older rock, the morainelike deposits stand higher. Thus there may be within a quarter of a mile a difference of 150 feet between the top and bottom of the formation. There is in the Eight-Mile Canyon area, within a distance

of 2 miles, a difference of 250 feet; west of Eddy (*E*) a difference of 200 feet; and north of Turner Butte (*T*) within a distance of 2 miles, a difference of 250 feet. The differences in elevation between the higher contact over a comparatively short distance are gradual changes, continuous in their direction.

The knob and kettle topography is striking, considering the area in which it occurs, though the relief is very low between the top of the knobs and the bottom of the kettles. Undrained pockets, in which for a short period of the year sufficient water stands to maintain a fairly good growth of grass and perhaps a few stunted bushes, are common. Because of the low relief and the general deceptiveness of the sloping surface on which the deposits lie, it is necessary in many cases for the observer to complete the circuit around a pocket or kettle or to take level readings from his point of observation to make certain that the pocket has no drainage outlet. The pockets of greatest depth were found in the northwest corner of township 2 north, range 22 east, where a relief of 30 feet frequently occurs. In general over the rest of the area the relief averages about 15 feet, ranging between 10 and 20 feet. Such undrained pockets occurring together in clusters, forming extensive areas of knobs and kettles, may be properly called morainelike[3] deposits.

In addition to the perfect kettles there are some which have a drainage outlet. To breach a kettle completely with a lake or silts first it must be filled and then develop a permanent drainage. One factor in the process is the character of the material of which the deposits are formed. If, as in the Eastern States, the kettle is formed of rock flour and glacial clay, then the pocket is impervious and becomes a receptacle for water, which may eventually spill over and breach it. In the Arlington area, however, the knobs and kettles are formed of gravel and sand with a minimum of silt and clay, so that they are quite pervious and, with the exception of a very few unusual ones, do not hold any considerable amount of water. Moreover, they occur in an area where the rainfall is only about 10 inches a year. We conclude, therefore, that the subdued knob and kettle topography is not due to normal erosion.

An explanation of the above problem is found on the western side of the Rhea area (*RH*), where knob and kettle topography, with a relief of 30 feet, gradually changes westward into one in which the pockets are all drained; farther west the material extends out in a series of fingers.

[3] Localities where such topography can be seen are as follows: Section 5, township 2 north, range 22 east; section 21, township 2 north, range 20 east; section 17, township 2 north, range 20 east; township 3 north, ranges 21 and 22 east, northwest of Turner Butte.

The western half of the large Diamond deposit displays subdued knobs, a number of stream channels, and on the western and southern edge a fingerlike fringe.

The knobs are steepest on their eastern sides and their slope is gentlest on their western sides, particularly in the Eddy area (*E*) and in the eastern part of the Diamond area (*D*). In each of the three areas the perfection of the knob and kettle topography increases as one goes from the east towards their western third, beyond which their west and south borders are subdued, channeled, and finally, at their extreme edge, frayed.

RELATIONSHIP TO OTHER FORMATIONS

Most of the deposits lie on the Arlington formation. This formation consists of stream gravels and lake beds and lies horizontally and unconformably on the Columbia River basalt formation. The Arlington formation was eroded to some extent previous to the deposition of the morainelike deposits. Figure 2 shows erosional remnants of the Arlington formation which protrude through the deposits. In addition the deposits lie against large knobs and cliffs of Arlington beds, as for instance, Turner Butte (*T*). The Eddy deposits (*E*) lie on the south side against a south-facing Arlington formation cliff. An almost continuous lake bed cliff, broken only at the head of Jones (*J*) and Blalock (*B*) canyons, extends from just south of Arlington along the north and west edges of the Eddy and Diamond deposits all the way across to John Day River (figure 2). The bottom of this cliff is basalt; the top, eroded back, is Arlington formation.

All cliffs exposing eroded edges of the Arlington formation rise above the general level of the deposits. It is clear then that the deposits were laid down after a short but very effective period of erosion affecting the Arlington formation. As the upper part of the Arlington formation is composed of gravels, the morainelike material in most places lies on these gravels. The deposits apparently occupy an erosional pathway in the Arlington formation which begins at Heppner Junction (*H*) and extends southwestward to McDonald (*M*) (figures 1 and 2). Both to the north and to the south of the morainelike area lie higher uneroded Arlington beds. We are not concerned particularly with the higher area to the south, but it is very essential to remember that lying between the present Columbia River and the lowland is a strip of Arlington beds rising at least 100 feet in places above the level of the deposit. South of this residual erosional remnant there was once a broad pathway cut in the Arlington beds, as shown in figure 3.

The agency that brought the morainelike material into this lowland deposited it chiefly in a low channel and banked it up against the cliffs of Arlington formation. It is banked higher against the cliffs and against the islands that occur in the channel than in the channel itself.

The Eight-mile (*EC*) deposit, west of the lower part of Eight-Mile Creek, lies apparently on basalt [4] and hills of basalt protrude through it.

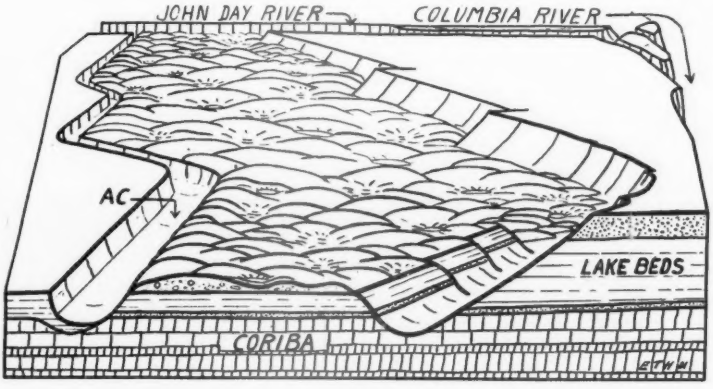

FIGURE 3.—*Morainelike Deposit in abandoned Channel South of Columbia River*

A diagrammatic sketch of the Diamond deposit looking west from its eastern end. To the north (right) the Arlington formation (lake beds and gravels) is undissected and continued to the brink of Columbia River. To the south an old channel was cut in the Arlington formation soon after its deposition, through which Columbia River flowed to what is now John Day River, thence northwestward (compare with figure 2). In this old course an iceberg jam formed a deposit in part on the lake beds and in part on the underlying Columbia River basalt (Coriba). This ice jam served to dam the water on the reader's side, that is to the east, and this water eventually found its way around the ice jam on the south side, cutting Alkali Canyon. This discharge channel approximated the former course of John Day River (to northeast) and lies, therefore, partly in basalt and partly in Arlington formation. The diversion to the north is the present channel of Columbia River. After the deposition of the first morainelike deposit, water flooding over this area eroded additional channels such as that in the center of the view, which can be traced in the basalt where it extends under the deposit; thence it may be found in various areas, coming out into Alkali Canyon just about at the point of *AC*. Note in the upper right corner of the sketch the old courses of Columbia River into what is now John Day River.

Between Eight-Mile and Rhea areas is an exposure of basalt which has a rough, channeled appearance, as though it had been eroded recently by a large river. This channel can be traced across Alkali Canyon (*AC*), south of Eddy area, by Jones Canyon (*J*) to the southwest, where it

[4] **Basalt in this paper refers to the Columbia River basalt formation (Coriba formation) of Miocene age.**

seems to pass under the Diamond area, reappearing 2 miles to the south. Also, basalt is exposed in the channels at the west end of Diamond moraine. The basalt rims, when traced to the north, are continuous with the rim on Columbia River. A possible explanation of the relationships of the basalt, the Arlington formation, and the morainelike deposit is shown in figure 3.

Channels occur in the deposits but their description will be given with the discussion of origin.

FIGURE 4.—*Photograph of Erratic on the Rhea Deposit*

ERRATICS

Associated with the deposits are numerous erratics occurring in clusters. They are composed of limestone, slate, biotite schist, and biotite granite; the granite erratics are very abundant, those of limestone next, and those of schist and slate rare. Their truly glacial derivation is shown by angular shape, fine striations, and polished surfaces (figure 4); some of them are perched. One granite shows a highly polished face 10 feet across. The erratics vary in size from boulders as large as an automobile down to small pebbles; two standing side by side, for instance, were 12 x 8 x 8 feet, and 8 x 8 x 8 feet. Rocks of similar composition occur in the Blue Mountains, but the erratics, as a rule, appear to be foreign to Oregon.

Some erratics are deeply buried in the deposits and seem to have had a contemporaneous origin. They lie on the surface of the Dalles, Arling-

ton, and Columbia basalt formations. They occur on the uplands above 1,000 feet elevation in greatest profusion within a few miles of Columbia River, but are much less abundant on the uplands adjacent to Deschutes and John Day rivers. Although most common on the uplands, a few have been found in the river bottoms as far south as the 1,000-foot contour crossing on John Day and Deschutes rivers. They are very rare in Deschutes and John Day canyons but more abundant in the canyon of Columbia River. The erratics occur chiefly at the level of the morainelike deposit or higher, over a belt that extends as far east as Umatilla and as far west as Portland, and in a belt adjacent to several other tributary streams.

The number of erratics on or near the deposits is 50 times greater than in the erratic belt parallel to Columbia River and 1,000 times greater than in the erratic belt paralleling John Day or Deschutes rivers. This ratio is also true of the erratics in Chenoweth area.

COMPOSITION OF DEPOSITS

The deposits are composed essentially of unweathered gravels. These gravels are of many types of rock, including erratic-rock types and other rock foreign to this area. The gravels are stream-worn, rounded, typical river gravels—in fact, the same type of gravels that compose in part the Arlington formation.

CHENOWETH AREA

Fifty-four miles west of Arlington, also on the south side of Columbia River and on the eastern edge of the Cascade Mountains, is the Chenoweth deposit (figures 1 and 5). It lies on the north side of Chenoweth school above the junction with Brown Creek in sections 34 and 35, township 2 north, range 12 east, and section 3, township 1 north, range 12 east. Figure 5 covers an area of half a mile long by 300 yards wide.

The general features of this area are similar to those of Arlington area, including the knob and kettle topography, erratics, gravels, and preservation in an exposed locality.

The deposit lies at 1,198 feet elevation above sealevel—higher than the present general level of the Dalles formation—and rests almost entirely upon the basalt. The Dalles formation is composed of stream gravels, sands, silts, mud flows, pyroclastics, and intercalated lava flows. The last-named formation was built of materials derived from volcanoes of the Cascade Mountains in the Pliocene or Pleistocene, and lies unconformably upon the Columbia River basalt formation and under the great thick mass of Cascade Mountains andesite lavas. The Cascade Moun-

tains are built essentially of Cascade andesites. Previous to the deposition of the Dalles formation and the Cascade andesites, the surface of the Columbia River basalt formation extended with very little change from the plateau of central Oregon under the Cascade Mountains, a vol-

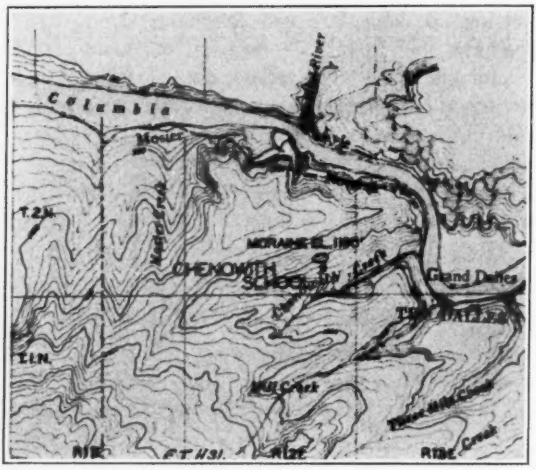

FIGURE 5.—*Topographic and geologic Map of Chenoweth Area*

The Chenoweth, or smaller area, is shown on the west side in figure 1. Note how Columbia River swings normally to The Dalles, makes an abrupt, abnormal turn to the northwest, and then cuts a channel that is the narrowest canyon along the entire course of the river in Oregon and Washington. This area, except northwest of Chenoweth Creek, is covered by the Dalles formation, which lies on the Columbia River basalt. Within the area of this map a synclinal structure in the Columbia River basalt strikes northeast and southwest through The Dalles, and an anticline, called the Ortley anticline, strikes through Lyle parallel to the syncline. Note that Chenoweth Creek has a barbed entrance to Columbia River. Along Chenoweth Creek the Dalles formation has been largely removed and just north of the old Chenoweth School is a small patch of morainelike deposit at an elevation of 1,190 feet. Topography by Hodge.

canic pile, to Willamette Valley or to the Coast Range of Oregon. The Chenoweth deposit was laid down after a post-Dalles period of erosion as shown by small erosional remnant patches of these beds in its vicinity. The west side of this deposit, too, is subdued and then frayed, and beyond the basalt shows shallow channels.

The erratics lie on top of the deposit, a number of them being deeply buried in it. Many of them are composed of granite, others of gneiss,

quartzite, limestone, or aplite. The water-worn pebbles of the deposit consist of the same materials, but a greater proportion of them are composed of quartzite.

The location of this deposit is peculiar. It lies up a tributary valley of Columbia River that is not in line with the direction of its present current nor tangent to the bend of Columbia River near The Dalles. In fact the entrance of Chenoweth Valley into Columbia River is barbed and is the only valley in the vicinity with a morainelike deposit.

The problem before us is to find the cause of the erosion of the Dalles formation, the channeling of the basalt, and the deposition of the morainelike material and erratics in this inaccessible Chenoweth locality and in the Arlington area.

ORIGIN OF THE MORAINELIKE DEPOSITS

GLACIAL THEORIES

The perfect morainelike topography of these deposits leads one to attempt to explain them as moraines formed at the edge of an advancing ice-mass. There are three possibilities: (1) that an ice-tongue extended from the nearest mountains directly to this point; (2) that a glacier from the Wallowa and Blue mountains followed the Snake-Columbia course; and (3) that a glacier forming a prolongation of the Pleistocene continental ice-sheet followed Columbia River down to this area.

The writer and his coworkers have examined every square mile within 20 miles of the north side and 50 miles of the south side of Columbia River from the Cascade crest eastward to Willow Creek. East of Willow Creek as far as Umatilla, traverses have been made every 12 miles as far south as the 18-mile line. In all of this area there is not the slightest evidence of any morainal topography nor any evidence of a glacier having once moved over the country. North of Columbia River is a high fault-scarp extending from the Cascade Mountains eastward almost to Umatilla, and no glacier could have crossed its crest without leaving some evidence of its passage. Our conclusions regarding the three possibilities given above are as follows:

(1) Wallowa Mountains have been deeply glaciated, and evidence of glaciation in the Blue Mountains, which stand just as high, will be found when they are carefully examined. Umatilla Mountains, a western prong of the Blue Mountains, probably were not glaciated. Cascade Mountains show evidence of three periods of glaciation.[5] If any of these moun-

[5] E. T. Hodge: "Late Tertiary climatic changes in Oregon." Monthly Weather Rev., vol. 58, Oct., 1930, pp. 405-11.

tains supported glaciers that were large enough and sufficiently long-lived to have moved over the upland surface to this locality, the evidence of their pathway has escaped our notice. It is unlikely that these mountains had glaciers large enough to extend more than a few miles beyond their bases.

(2) and (3) Several observers studying in the region along Columbia River east of Arlington have failed to find evidence that the valley had been occupied by a glacier. If such a glacier had reached Arlington area, then it must have been thick enough to spill over the canyon walls and should have left lateral moraines not only on the upland south of Columbia River, but also on the broad benches north of the canyon as well. Morainelike deposits occur on the south upland, but none on the north side. The deposits on the south side are not parallel to the river; at one point they are very close to it, and farther west a long distance away from it. The deposit looks more like the terminal moraine of a glacier that came from the southeast; this assumption as to source, however, was found to be untenable. The absence of lateral moraines on the north-side upland of Columbia River where the conditions of reception were equally good, the absence of any terminal moraine between the canyon walls and the complete absence of any evidence of glaciated canyon walls, all tend to prove that the deposits were not formed by a glacier in Columbia River valley. To this we have additional positive evidence which may be stated as follows:

In many places the Arlington formation comes to the very brink of Columbia River canyon. In fact, north of the area, and for some distance east and west, the Arlington beds overhang the south wall of the present canyon of Columbia River. The steep wall of the canyon carved in the Columbia River basalt continues upward as the same wall formed by the Arlington beds. The same is true of the north side of the river where Arlington beds lie on The Burn (*TB*). Clearly, the Arlington formation was laid across this area before Columbia River canyon was cut.

Arlington beds adjacent to Columbia River have suffered very little erosion. Farther south, however, the lake beds have been deeply eroded—in some places stripped off completely from the basalt. The almost perfect preservation of these beds adjacent to Columbia River canyon and their erosion in the belt of the morainelike deposits precludes the possibility of a valley glacier.

If the deposits were not formed directly by a glacier, what was their origin?

PROPOSED THEORY

Conditions to be met.—Any proposed theory must explain the following facts:

(1) The Arlington formation (lake and stream deposits) covered the area now occupied by the morainelike deposits and by the canyons of Columbia River and its tributaries.

(2) The Arlington beds were eroded at some distance from Columbia River but not in the area now occupied by the river.

(3) Dalles formation, for reasons not necessary to present in this paper, once covered the area into which Columbia River and its tributaries (including Chenoweth Creek) have since cut their canyons. It is well preserved near Columbia River, poorly preserved in the vicinity of the Chenoweth deposits, and entirely removed west and southwest of the Chenoweth deposits as far as the contact of Cascade andesites with the Columbia River basalt formation.

(4) Morainelike deposits were formed near but not contiguous to Columbia River.

(5) The morainelike deposits are composed of gravels derived locally from Arlington beds or transported from a distant source—in each case foreign material.

(6) The morainelike deposits are eroded, on the distal side with reference to Columbia River.

(7) The basalt is channelled beyond the eroded border of the deposits.

(8) The erratics associated with the morainelike deposits are abundant, but only a sprinkling of them occurs over a belt paralleling Columbia River and its tributaries.

The theory.—In another paper evidence has been presented to support a theory that Columbia River once had another course which left its present one at The Dalles and coursed southwest through the Cascade Mountains.[6] This course was dammed by the Dalles formation and formed Condon Lake. Condon Lake occupied a structural depression between Columbia fault-scarp on the north and Shaniko surface on the south. In Condon Lake the Arlington formation accumulated. The Arlington and Dalles formations later superposed Columbia River across Cascade Mountains in its present channel. Cascade andesites were laid down later and buried much of the Dalles formation.

[6] The complete evidence is given in a paper presented before the Geological Society of America, Dec. 29, 1930, vol. 42, pp. 923.

Before Condon Lake was raised to a level that provided an outlet for it by way of its present course it discharged imperfectly over the incompletely dammed former course. That is, as the dam was raised, Condon Lake level rose and discharge continued, if not along the former course, at least to the southwest. Only after the dam raised the lake level so high that it spilled over the Ortley pass, was the southwest pass abandoned. Later Cascade andesites have completely buried this older topography. There existed, therefore, near Chenoweth a baselevel for Condon Lake. The shallow water of that lake near Chenoweth, according to our theory, snagged icebergs.

After Condon Lake had found its final outlet and was drained, Columbia River cut down through the Dalles and Arlington beds into the Columbia River basalt. It cut into the basalt first at the Ortley anticline, producing another baselevel, upstream from which Columbia River was sluggish. The second place at which basalt was cut into below the lake bed was at the Klondike anticline just west of the Arlington area. The river began to meander over the lake beds; one meander-bend coming from the northeast did not make the sharp turn at Arlington (*A*) but continued in a broad arc southward, connecting with John Day River somewhere near McDonald (*M*). Along this course the river then began to remove the Arlington formation. Here it eroded a canyon about 400 feet deep and 5 miles wide. While the river was occupying this canyon there came down its flooded course during a period of high water a great flotilla of large icebergs. The icebergs probably came from the continental ice-front, as the erratics appear to be foreign to Oregon. There were many places upstream favorable for the stranding of these icebergs; that they did not strand there was probably due to their buoyancy (upstream they would have still retained a large proportion of ice compared to their load) and to the depth of water still remaining in Umatilla basin. Somewhere as they came downstream they must have grounded as a result of (1) a decrease of buoyancy caused by more rapid melting of ice than shedding of load, or (2) shallower water in the river. We need not assume that all the icebergs melted at the same rate, as it is required that only a few should snag in order to serve as a barricade that would capture the others.

The two localities where such an accumulation of icebergs must have taken place were at the two baselevels (where the basalt stood highest and was first exposed by removal of the Arlington beds). At the one on the east side of the Cascade Mountains along the present canyon of Columbia River we find no morainelike deposits, a fact so significant as

to require special discussion. The other, near the mouth of John Day River (*JD*), is simpler to explain. It is likely that the icebergs snagged at the latter place, where the Arlington formation once just buried the underlying basalts; where, in what is now the lower portion of John Day River, Columbia River had cut down into the basalt and therefore was confined in a narrow intrenched channel. Here no iceberg, not even a small one, could slip through the narrow, shallow chute.

Under the theory here proposed, icebergs accumulated in this portion of Columbia River channel, filling it for a distance of 20 miles upstream (that is, the distance occupied by the morainelike deposits). Twenty miles of ice would form an effective dam for a river and pile up the water behind it throughout the long stretch of the Columbia River course, forming a tremendous pressure by water and ice and crowding the icebergs tightly into a mass. It would produce, not an ice stream, but an ice and water stream; not an ice shove but an ice and water shove; a sort of reversed glacier.

This mass of ice under such pressure would have the same effect as a true glacier and would produce a deposit like a ground moraine, creating the deposit out of the material carried and that at hand, which would be largely river gravels. In this case the local gravels would be those gravels exposed by erosion at the base of the Arlington formation (figure 3). Behind such an ice dam an enormous body of water must have accumulated, as it is not likely that the icebergs melted in less time than several weeks.

The backed-up water must have attempted to seek other outlets, one of which was around the south side of the dam. The enormous volume of water deflected in this direction must have quickly cut through the Arlington beds down into the Columbia River basalt, providing thereafter an outlet along this course (*AC*, figure 3). This channel was cut before the ice melted completely and stranded its erratics. Another channel was cut by water deflected around the north side of the deposit at the river bend at Arlington, taking a straight course over the Arlington formation to Quinton (*Q*) and to John Day River (*JD*). The new channels cut by the dammed waters superposed the river over new courses.

Detailed discussion of theory.—In attempting to discover the effects resulting from the deposits we must go back to the oldest drainage surface that can be found. To this end we examine the rim-rocks of the Columbia River basalt along Columbia River and find that they are continuous, showing evidence of no buried valleys. In the tributary

valleys adjacent to Columbia River we find that the streams are incised in exceedingly youthful canyons. Furthermore, we find no mendips of basalt protruding through the Arlington formation on either the north or the south side of Columbia River. Farther south, however, we find a different set of conditions. There we find numerous mendips protruding through the beds. For instance, in the vicinity of Turner Butte (*T*) there are four, and east of Shutler (*S*) there is one. If we follow along the canyon walls of Willow (*W*), Eight-Mile (*EC*), Alkali (*AC*), and Rock creeks (*DM*) we find the basalt continuous along Rock Creek and thence down John Day River with no evidence of buried valleys. Tracing the basalt up Alkali Creek, we find between Rock Creek and Shutler a stretch of the canyon wherein the Arlington formation reaches to the valley bottom. Also, we find many stretches in Eight-Mile Creek canyon wherein there are no basalt rocks, and near Shutler several localities where the basalt seems to be absent. Further, the elevation of the basalt decreases rapidly from Rock Creek northward or northeastward, whereas northwestward along John Day River or towards Columbia River, it increases. The remarkable contrast, therefore, between the perfect preservation of the upland surface of the basalt along the lower John Day and along all of Columbia River and its imperfect preservation several miles south of Columbia River suggests that before the Arlington beds were deposited John Day River flowed northeastward. Just east of the area in the Umatilla Basin at the base of the Arlington formation we find deposits of gravel, part of which may be the accumulation brought to this depression at that time by John Day River.

Lying on the surface of the basalt are the Dalles and Arlington formations, which prove the former presence of Condon Lake, as do also the superposed courses of the streams and lake shorelines.

Condon Lake was at least deep enough so that the lake deposits that were formed in its bottom rose to a level of 1,750 feet. The water rose high enough to spill over the top of Alder Ridge (*AR*), as shown by the deposits left upon its surface, and to bury beneath the lake beds the crest of a fold in the basalt just west of the mouth of John Day River.

One can not examine the Arlington beds lying on the Columbia River basalt surface without coming to the conclusion that they were once continuous over the Columbia River area. The proof of this is as follows:

(1) The surface of the Columbia River basalt underneath the Arlington beds on the south side is of the same elevation as the Columbia River basalt in The Burn on the north side of Columbia River. The lower

contact, therefore, of the Arlington formation is the same on both sides of the river.

(2) The surface of the Arlington formation on both sides of the river is identical.

(3) The beds are continuous up to the brink of the canyon.

(4) The beds are least eroded in a belt adjacent to the Columbia River course. In fact they are best preserved in the area north of the morainelike deposit to Columbia River, interrupted only by the canyon and thence north to the great fault-scarp.

(5) If the canyon of Columbia River is older and was filled and reexcavated we should find Arlington beds somewhere tucked away in reentrant curves of the present gorge. These we do not find. They occupy only the high levels above 750 to 1,000 feet.

(6) There is evidence of superposition of Columbia and John Day rivers by some agency, and the only agency available is the Arlington formation.

(7) Finally lower John Day River, Columbia River, and Blalock (*B*), Lang (*L*), Jones (*J*), and Quinton (*Q*), tributary canyons are clearly post-Arlington formation in age, as they cut both the lake beds and the Columbia River basalt, exhibit no buried canyons, and show evidence of extreme youthfulness. The conclusion is clear that the Arlington formation was deposited on a basaltic surface into which at that time Columbia River had not cut its canyon and which was only slightly eroded. If this be true, then we must look for some explanation which would permit the presence of a continuous surface of the Arlington formation upon which the morainelike deposits were laid down. If it can be proved that these beds covered the surface now occupied by Columbia River we may dismiss all possibility of a valleyway for a glacier.

The Arlington beds smoothed out the irregularities of the basalt topography except for a few hills such as Turner Butte (*T*), Diamond Butte (*D*), and others that rose above its general level. The pre-Arlington valleyway of John Day River was buried. The Dalles formation for similar reasons also covered the area occupied at present by Columbia River.

Let us consider for a moment the generally accepted antecedent theory of Columbia River. Under this theory Columbia River would (1) have had a low, level course in its present canyon through the Cascade Mountains (figure 1 and 5); (2) in this canyon, at least on the favorable areas to either side of the water gap through the easternmost fold (Ortley) and especially in the lowland upstream, we should find some moraine-

like material and a few erratics. On the contrary, in this critical section through the canyon of Columbia River there are neither erratics nor deposits—a remarkable fact because more favorable sites occur here than at Arlington.

In contrast to the present canyon of Columbia River let us examine Chenoweth Valley. This is a valley barbed to the sharp north-twist of Columbia River. It and other tributaries are in line with the southwest course of Columbia River, and both river and tributaries are in line with a syncline of basalt. This syncline is now buried by the Dalles formation except where eroded along Chenoweth Creek. Along Chenoweth Valley the basalt is laid bare for many miles and the deposits and many erratics lie on this exposed surface. The erosion of the morainelike deposits, of the Dalles formation, and of channels southwest of the deposits must have resulted from water flowing to the southwest. This evidence seems to prove that immediately after the drainage of Condon Lake the old outlet was still open enough to direct a current but not enough to allow the free passage of icebergs.

The lavas of the Cascade formation lie on the Dalles formation, and they were perhaps the agency that later completely closed the old outlet and forced the waters of Columbia River over the Dalles formation at the Ortley anticline and out along its present course.

Thus in both the Arlington and Chenoweth areas the course of Columbia River was not as it is today. Were the older courses such as to cause the grounding of icebergs, resulting in the formation of the morainelike deposits?

The erosion in the Arlington area shows the former course of Columbia River. It is a significant fact that the deposits lie east of the upwarped basalt (Klondike anticline). The Klondike axis lies west of John Day River, crossing the lower course as shown in figure 2. From this anticline eastward there is a descent of the basalt surface to the nadir of Umatilla Basin. The deposits are perched just below the crest on the east side of this fold, east of where the basalt must have been first exposed by erosion of the Arlington beds.

The deposition of the icebergs, not in isolated areas, but in two great masses in the channel of the old Columbia River, served to dam it, creating secondary lakes east of Chenoweth and in the Umatilla Basin. The water levels of the second-stage lakes were not as high as that of Condon Lake, for in the case of the latter, deposits were left on the top of Alder Ridge. These lakes could not have been much higher than the top of the present deposit. The water was not high enough to overflow the Arling-

ton beds except upon a few occasions, and was never deep enough on the Arlington surface to float icebergs. It is possible that the two lakes were not contemporaneous and that Chenoweth Lake was formed first; if so it did not extend eastward far enough to flood the Arlington area.

The Chenoweth deposits are clearly only a remnant of a once larger deposit and most of the details of its erosion are gone. The Arlington area, however, preserves many minute details, so that we may clearly determine the steps involved.

The erosional effects on the Arlington deposit may be divided into three stages: (1) a sheetflood which transgressed its surface and destroyed its western and southern margins but did not rise high enough to overflow the walls formed of the Arlington formation; (2) the development of lateral erosional channels; and (3) the formation of additional deposits.

Before discussing these stages we should point out that the erosional effects were not caused by ordinary agencies. If they had been then the deposits west of Alkali Canyon (*AC*) should be the most eroded, as this area has by the largest number of streams, and the deposits east of Alkali Canyon should be the least eroded because that area is remarkably dry, being almost untouched by upland streams. Further, if the erosion resulted from sheets or floods of water from the present-day Columbia River or John Day River, then deposits adjacent to the Columbia or John Day rivers should be the most eroded.

With these preliminary remarks let us proceed to the detailed discussion of the three types of erosion.

(1) In the first stage the iceberg dam blocked water which eventually spilled over the surface of the deposit as a sheetflood. Proof of this is the scabland topography existing just west of Rhea (*RH*). The steps of this scabland go westward and show in the basalt surface the evidence that a large volume of water swept across the area. It crossed this area and continued across what is now Alkali Canyon (sections 2, 3, 4, and 5, township 2 north, range 21 east) and thence westward, eroding the pathway between Eddy and Diamond deposits. Continuing westward it swept across the northwestern end of the Diamond deposit, scarring it, and reached John Day River. A distributory cut southward to Alkali Canyon (*AC*), joining it where the latter makes its sharp south bend. There are a number of evidences of this fact: (*a*) the erosional remnants east of Alkali Creek are much more detached than those to the west; (*b*) scarred upland channels lie between the deposits west of Rhea and again between Eddy and Diamond deposits; (*c*) an erosional channel

occurs in the deposit at the west end of the Diamond deposit; (*d*) these erosional channels at the northwestern end of the Diamond deposit show definite relationship with the cliffs, knobs, and mendips which exhibit clear evidence that currents of water were deflected; (*e*) the western and southern edge of all of these masses is much more frayed than the eastern side. In other words the deposits are frayed on the downstream side in regard to John Day River, and on the downstream side in regard to the Alkali Canyon route.

(2) The second stage no doubt was concurrent in part with the first stage. With the lowering of the ponded waters there came a time when no water was able to flow over the surface of the deposit except during the repeated flood stages. Finally, as lateral channels around the deposit were perfected a drainage was provided for the ponded waters.

The water diverted by a mass of ice-moraine 20 miles long, 5 miles wide, and at least 400 feet in its thickest section must have gone in part around the southern edge. The topographic map (figure 2) clearly shows a series of channels definitely paralleling its southern edge, via Willow Creek (*H-W*) to Rhea (*RH*), Eight-Mile Canyon (*EC*) to section 21, township 2 north, range 22 east, thence across to Shutler (*S*) and Alkali Canyon (*AC*); Alkali Canyon from Shutler to Rock Creek (*D-M*); and Rock Creek to John Day River (*M-JD*).

Willow, Eight-Mile, and the Alkali creeks have cut deep canyons in the Arlington beds that surpass in size, depth, and width the following canyons cut across the moraine: Alkali, north of Shutler (*S*), Jones (*J*), Lang (*L*), Blalock (*B*), and Quinton (*Q*), or elsewhere into Columbia River basalt. The southside canyons are characterized by broad, sweeping curves and flat-bottomed valleys. Willow Creek enters Columbia River in a barbed confluence; Eight-Mile Creek is a direct projection of Willow Creek; Rock Creek is united with Alkali Canyon by a valley wherein the divide occurs between Eddy and Shutler at bench mark 525, and throughout its course southwest of this point is a large, open, widely swinging, abandoned canyon, which is occupied by no stream. Alkali canyon is one of the most unusual canyons that the writer has studied. From Arlington upstream the canyon is youthful, its grade rising to Shutler, where it abruptly opens into a broad, flat, sweeping-curved valley, the grade of which changes to the southwest. The change of grade is hardly measureable because of lateral washes, playa flats, and other obliterating features, all due to the absence of any stream. Its junction with Rock Creek is normal.

The south-side watercourse is in part identical with the pre-Arlington course of John Day River. If we were to remove the Arlington formation we would find this old course from the vicinity of bench mark 466 (south of *M*) on John Day River northeastward to the lower part of Eight-mile and Willow Creek canyons. The former depth of the old course was only 100 to 250 feet below the basalt surface and the grade descended from southwest to northeast.

The reversal of water along the old course of John Day River, that is, Willow, Eight-Mile, Alkali, and Rock creeks, was not an accident. The deposition of the morainelike deposit had been determined by the older course of Columbia River, which in turn was dependent upon the course of John Day River into the shrinking Condon Lake; the latter course, in turn, was the normal course of a river on beds laid on a dip-slope. Water around the outer edge of the deposits would naturally cut down at their border and into the old John Day River course. In the old course the large volume of diverted water was favored by the easily eroded Arlington beds, hence their swinging arcs. In this reverse course Columbia River did not necessarily occupy the exact old course of John Day River, but was in places superposed. This explains the appearance and disappearance of the basalt in the walls of Alkali Canyon.

The southern course was favored by Columbia River because it is a sweeping curve in continuation of the course of Columbia River east of Heppner Junction (*H*).

Against these favorable conditions are to be placed some unfavorable factors: (1) once the Arlington formation was cut through, the basalt north of McDonald (*M*) formed a temporary baselevel; (2) the southern course was longest.

Assuming that at first the prow or eastern end of the moraine deflected all the water by the southern route, a deflection on the north side was inevitable. The southern upland channel at that time could not be used because of its shallowness; it was not much deeper than the lake beds due to the McDonald (*M*) baselevel. Clogging of the southern course, if only for a short time, must have diverted the water around the north side of the ice-morainelike mass.

At least some of the water had to pass around the north side and no doubt used the course now occupied by the present Columbia River. The exact northern course taken was predetermined, as it appears that an old valley must have existed here draining this area 15 miles wide and 25 miles long eastward into the Umatilla Basin (a residual portion of Condon Lake). This old channel on the Arlington formation is shown

by the barbed character of the canyons on the north side of the present Columbia River, particularly that of Chapman Creek, opposite Lang canyon (*L*), indicating a reversal of drainage from east to west. The water spilling around the north side of the Arlington morainelike deposit cut down quickly through the lake beds establishing its course to Quinton (*Q*) to the present John Day River (*JD*). The course of Columbia River did not make the sharp northwest bend, but continued westward into John Day River in the abandoned channel shown at *Q* (figure 2).

Both the north and south diversion channels were defective because of their shallowness, the southern more so than the northern. This was because the united channels northwest of *Q* (figure 2) in the lower John Day River was cut into the basalt of the Klondike fold; here a narrow channel was cut in basalt. The Alkali route was longest and was therefore more often dammed; each blocking of the southern channel fixed more definitely the course of Columbia River in the shorter northern route.

Only upon occasions of extreme flooding did the water rise high enough to overflow the walls of the original valleys cut in the Arlington formation. When the flat Arlington surface was flooded, the water spread widely as on a floodplain. The definite limit of the flood, as determined by the slope, was the Columbia scarp about 10 miles north and the edge of Arlington surface against the Columbia River basalt surface about 20 miles south, but the flood waters certainly did not spread north and south as far as this. When the floods spread, the floating icebergs must have been stranded within a short distance of the valley walls from which they escaped, because of the shallowness of the flood. This is shown by the distribution of erratics. The waters spread over the border tracts were not confined and flowed slowly and with little depth; hence they did not scour nor erode and certainly cut no new channels. The new channels were all cut where the floods were confined within the older valleys cut in the Arlington formation.

(3) We now come to the third stage in the erosion of the morainelike deposits. In conformity with our theory we should expect that in the course of time a new crop of icebergs might have become stranded in the new channels and forced the flooded distributaries to send their water over the deposit. If such were the case additional icebergs must have been stranded on the higher lands, that is, the Diamond area, especially in the western part of this deposit. The second crop of icebergs could not have been as thick as the first nor as effective, because (*a*) the canyon walls were lower, and (*b*) these walls were breached by two lateral drain-

age channels, and (*c*) the newly created discharge channels also enabled some of the icebergs to escape. With the melting of the icebergs the sheetfloods must have quickly subsided, as the flood waters were immediately discharged by way of prepared channels. For these reasons, too, the later deposit has been more perfectly preserved than the first.

The second morainelike deposit is very thin in comparison with the first and barely succeeded in places in blocking the channels cut in the first deposit. Excellent evidence has been found to prove the burial of

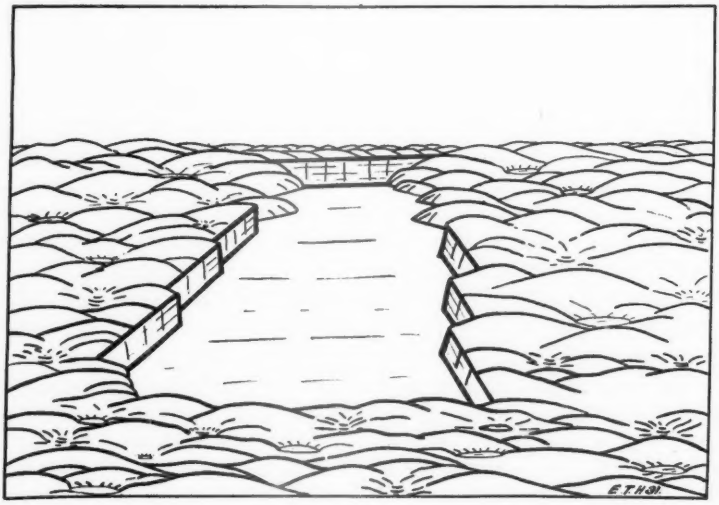

FIGURE 6.—*Partially buried interdeposit Erosion Channel in Diamond Area*

This diagrammatic sketch is a portion of Diamond deposit just to the right of *AC* (figure 3). We are looking to the north. It shows an uncovered portion of the channel cut in the first deposit by waters flooding over its surface. The flooding waters cut this channel through the first deposit into the Arlington formation and down into the basalt. A later deposition of morainelike material buried this channel, as shown on the two sides of the pocket in the background and in the foreground.

interdeposit channels. Thus, the channels already described [7] were buried.

The pocket shown in figures 2 and 6 northwest of Alkali Canyon (*AC*) is an undrained depression resulting from the failure of the second de-

[7] A channel is exposed from bench mark 525, section 10, township 1 north, range 21 east, then in sections 9, 8, 7, and 18, and again in section 24, township 2 north, range 20 east (figure 3). This north-south channel is 2 miles from, and in line with, the channel leading to Jones Canyon. It turns southwestward in section 18, township 2 north, range 21 east, is exposed again in sections 25 and 36, township 1 north, range 20 east, where it opens into Alkali Canyon.

posit to completely bury a channel. This channel was cut through the morainelike deposits and the Arlington formation, and into the basalt. Other good channels occur at the west end of the Diamond area northwest of Turner Butte (*T*) (figure 2).[8]

The northernmost channel is clearly blocked in its lower portion by a later deposit and shows evidence of the two deposits. The lower portion of this channel is cut through lake beds and into the basalt. The morainelike deposit lies in the channel on basalt below the level of the lake beds. This long, narrow channel, therefore, appears to have been cut by water flowing over the first deposit. At the western edge the water cut deeply through the deposit into the Arlington formation and the basalt. Then, at a later period, more morainelike material blocked the channel in its upper portion, forming pockets, and in the lower portion filled the channel with deposits almost up to the level of the Arlington beds.

Other effects of the deposits.—Repetition of the clogging of the channels cut over or around the morainelike deposit would have resulted in their eventual washing away. This did not happen because of the perfection of the north and south channels. The shortened course from Heppner Junction (*H*) to Quinton (*Q*) and then across to John Day River soon diverted all the water of Columbia River.

The depth of the channels of the rivers at that time can be approximately determined by the depth of the south channel, which where it enters Rock Creek (*D*) is 728 feet above sealevel, a few feet below the lower contact of the Arlington beds and just deep enough to cut into the Columbia River basalt. The channel at Quinton (*Q*) is 720 feet in elevation in its lowest portion. At these elevations, when both streams were being superposed, it is evident that the shorter northern route had the advantage. This advantage was not so great but that clogging must have occurred and diversion of water resulted either around the south course or by some new course. That a new course was eventually chosen is shown by the second abandoned channel north of *JD* (figure 2) (in township 3 north, range 18 east). This channel in turn was blocked and

[8] Beginning southwest of the Blalock Canyon road in section 20, township 2 north, range 19 east and extending southward into section 29, thence westward into section 30, and continuing into section 36 of the next township, is a channel. This channel is continuous except for a very well-developed pocket in section 30. Another channel begins in section 32 in a pocket and is continued in section 31, township 2 north, range 20 east; it continues also into section 36, township 2 north, range 19 east and section 1, township 1 north, range 19 east. The latter channel lies entirely in morainelike deposits and only in township 1 north, range 19 east cuts down into the basalt, no Arlington beds being visible except in a portion of its north wall.

a further shift northward to its present course was taken by Columbia River.

In the meantime Columbia and John Day rivers had been cutting deeper into the basalts and lowering the baselevel just west of their present confluence. When both streams had cut channels into the basalt their courses were fixed and the other channels abandoned. This explains the curious sharp southwest bend at Arlington, thence its straight course west, thence the exceedingly sharp bend to the northwest, with another deflection to the southwest.

Erratics.—The erratics occur almost entirely outside of the canyons on upland above 1,000 feet elevation. They are most numerous in the vicinity of the morainelike deposits, less abundant along Columbia River as far west as Cascade Mountains and along Chenoweth Creek, even less abundant along John Day and Deschutes rivers, and absent along the new course of Columbia River through the Cascade Mountains. Their presence in the canyon bottoms offers no problem but their presence on the uplands above 1,000 feet requires a special explanation.

Before the Cascade Mountain basalt baselevel was fully exposed and while Columbia River was flowing over an Arlington-Dalles formation surface, floods must have been frequent especially in the winter season. These floods also must have been increased by iceberg dams especially in the winter season at Arlington and Chenoweth. Such dams caused the river to be blocked and flood areas to be created. In the flood areas, smaller icebergs floated, melted, and shed their erratics, which dropped onto the material below. Those that landed on the morainelike deposits naturally sank down into the sediment some distance and give us the impression, today, that they were buried in the deposit. With the breaking of the dam the flood waters rushed down Columbia River to the newly created, narrow, and shallow pass in the Cascade Mountains (Lyle) where they were held back. The flooding Columbia then passed its flood waters into its tributaries just as it does today into Willamette River. The flood under such conditions moved up the tributary canyons, and reversed the current in Deschutes and John Day rivers. The reversed currents carried some berglets up these rivers, where in turn they shed their erratics on uplands adjacent to the streams. Thus we may explain, under this theory, the erratics on the upland walls of John Day and Deschutes rivers contemporaneous with the morainelike deposits.

The erratics that now occur in the river bottoms probably are the result of undersapping of the lateral walls caused by canyon cutting, and their catapulting into the lowlands below. Some in the valleys, of course, may

represent human transportation. Such strange-looking boulders in a land where the Indians are known to have been interested in carving rocks must have been objects of interest and may have been rolled down into the river bottoms at a very recent period. For instance, a large erratic at Sherars Bridge, about 40 miles up Deschutes River, has Indian carvings on it and is associated with their legends.

The erratics are not older than the morainelike deposits, and their age is therefore pre-Columbia River canyon. If the erratics and morainelike deposits can be correlated with Pleistocene glaciation, then Columbia, John Day, and Deschutes canyons are Pleistocene and Recent in age.

The gravels in the morainelike deposits were derived from the Arlington formation, and were carried down Columbia River by water. Both gravels and erratics are foreign in origin, and only slightly weathered. These facts imply a late Pleistocene age. On the other hand, the deep canyons which Columbia River has cut suggest a long period of time, the exact amount being for the present a matter of individual judgment. The writer, basing his opinion on other studies in the upper Deschutes Canyon, concludes that evidence of the gravels and erratics should be given the greatest weight and therefore that the canyons were cut in the late Pleistocene.

Additional evidence may be adduced to support the view that the erratics are older than the canyons. If they had been scattered over the upland after the canyons of Columbia, John Day, and Deschutes rivers were cut, then we must search for the dam that raised the flood waters at least 1,200 feet and forced them upstream as far south on John Day and Deschutes rivers as the 1,000-foot contour line. Detailed mapping of Columbia River canyon has disclosed no such dam. The great landslide at Cascades did not raise Columbia River level more than a few hundred feet.

Summary

Morainelike deposits of unusual character occur isolated in north central Oregon and have an important bearing on the history of Columbia River. The deposits were formed by iceberg jams in constricted and now abandoned channels of Columbia and John Day rivers during Pleistocene time, when they flowed over a surface of stream gravels and like beds lying on the Columbia River basalt. The deposits played an important part in diverting these rivers into new courses, the last of which were entrenched deep enough to superpose them onto the underlying basalt, into which they have cut their present canyons.

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